OVERVIEW

A SCIENCE ROADMAP FOR AGRICULTURE

7

Seven challenges to meeting our nation's agricultural goals

be competitive in a global economy

add value to our future harvests

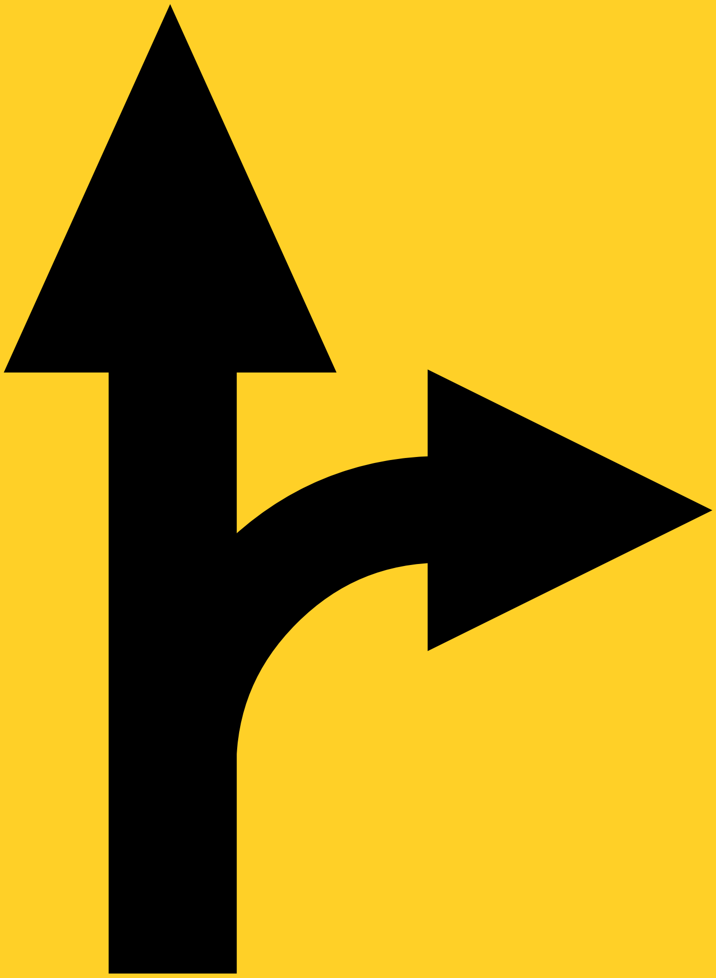
adjust agriculture practices to a changing climate

be good stewards of the environment and natural resources

make our agricultural enterprises profitable

make our families and communities strong

improve foods and processing for better health and safety



How can we meet the needs of diverse stakeholder groups?

Prepared by the
National Association of State Universities and Land Grant Colleges (NASULGC)
Experiment Station Committee on Organization and Policy (ESCOP)

DRAWING THE ROADMAP

Our rapidly evolving world of science and agriculture calls for a new approach in defining the needs and setting the priorities for research and education at both regional and national levels. To that end, the Experiment Station Committee on Organization and Policy (ESCOP) has formulated "A Science Roadmap for Agriculture[1]." The Roadmap sets forth seven challenges, each with under-girding goals on which the agricultural science research community must focus. These challenges relate to developing new products and markets, climate change, the environment and natural resources, profitability and competitiveness, families and communities, and food safety and health. Meeting these challenges and achieving the Roadmap's goals will result in increased success for the U.S. food and agriculture system, and for increased stakeholder and consumer satisfaction.

The Experiment Station Committee on Organization and Policy (ESCOP) developed its Roadmap with support from a task force of nationally recognized scholars that charted the major directions of agricultural science over the next 10 to 20 years. The task force assessed the scientific feasibility of meeting the needs of diverse groups of stakeholders ranging from the food production and processing sectors to consumers and the general public. This effort included prioritizing stakeholder needs; determining the scientific feasibility of solving the most important needs with current scientific methods and tools; and predicting the positive impacts of successful research outcomes. The resulting "Science Roadmap for Agriculture" will assist decision-makers and advocates for the research and education system, as they mobilize and plan the allocation of resources for future program areas.

THE CHALLENGES

New Products and Markets

Challenge 1. *Develop new and more competitive crop products and new uses for diverse crops and novel plant species.* Our science must focus on improving the quantity and quality of crop biomass and the efficiency of agriculture production; conceiving technologies that improve the processing efficiency of bioproducts such as biofuels; developing new products, uses, and markets; and supporting the development of marketing infrastructure for bioproducts.

Challenge 2. *Develop new products and new uses for animals.* Our science must focus on improving existing technologies and developing new ones to improve production efficiency; improving the nutritional value of meats and the value of other animal products for producers and consumers; developing innovative technologies to soften the impact of animal agriculture on the environment; and developing new and enhanced technologies to improve the welfare of animals processed for food.

Climate Change

Challenge 3. *Reduce the risks of local and global climatic change on food, fiber, and fuel production.* Our science must focus on slowing the rate of global climate change by storing more carbon and nitrogen in soil, plants, and plant products; minimizing the effects of climate change on crop and livestock production; integrating weather forecasting, market structure, and crop and livestock management systems to optimize production of food, fiber, and fuel; and developing comprehensive models to assess the social and economic impacts, risks, and opportunities for agriculture of global climate change and extreme weather.

The Environment and Natural Resources

Challenge 4. *Provide the information and knowledge needed to further improve environmental stewardship.* Our science must focus on developing better methods to protect the environment – both on and beyond the farm – with cropping systems that engage agroforestry, phytoremediation, and site-specific management; decreasing our dependence on chemicals that harm people and the environment by adopting effective strategies to manage crops, weeds, pests, and pathogens; finding alternative uses for industrial and agricultural wastes; and developing economic models and incentives that ensure environmental stewardship is encouraged.

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[1] *Prepared by the National Association of State Universities and Land-Grant Colleges (NASULGC) Experiment Station Committee on Organization and Policy (ESCOP). November 2001. The roadmap can be found on-line at http://www.nasulgc.org/comm_food.htm*

Profitability and Competitiveness

Challenge 5. *Improve the economic return to the producer.* Our science must focus on designing decision-support systems for farms that employ risk-based management, giving full consideration to small-, medium-, and large-scale enterprises; developing sustainable production systems that yield profits and protect the environment by integrating crop and livestock production; improving our understanding of how local, regional, national, and global economies affect the economic return of U.S. producers; and improving strategies for community-supported food production systems.

Families and Communities

Challenge 6. *Strengthen our families and communities.* Our science must focus on learning how to harness leadership to help rural communities solve problems; finding ways to stimulate entrepreneurship and business development in rural communities, along with finding new forms of economic activity built around regional trade associations, rural cooperatives, and local production networks; formulating strategies for building coalitions among environmental, labor, and community development groups to facilitate democratic social change that ensures families have access to food, healthcare, education, social and human services; and finding strategies that enhance the well being of families and individuals.

Food Safety and Human Health

Challenge 7. *Ensure food safety and health through the entire food-production chain.* Our science must focus on eliminating food-borne illnesses; improving the nutritional value of foods; developing technologies to create health-promoting foods; and fashioning better methods to educate individuals in making informed food choices. The potential threats to our food system from terrorist activities are real and both our animal and plant systems are vulnerable. Science must play a role in both protecting our food system from intentional contaminations as well as develop appropriate responses to minimize the impacts on the food-production chain.

$2.1 billion are needed to support nearly 5,200 additional Scientist-Years.

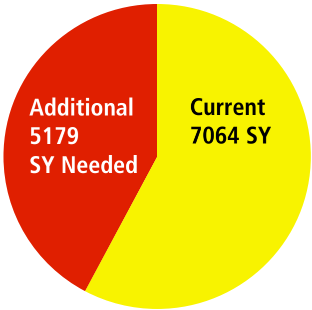
$4.5 billion are needed to support high quality scientific research.

Increased federal investment in the base programs of the Land Grant University partnership is essential.

A COMMITMENT TO THE FUTURE[1]

To navigate this Science Roadmap, and ensure that the food and agriculture system meets future needs, the national agricultural research system will need to harness significant new resources: nearly 5,200 additional Scientist-Years[3] (see Figure 1) and a total of nearly $6 billion in new funding will be needed to ensure that the existing U. S. food and agriculture system is sustained and expanded to meet future stakeholder and consumer needs.

Figure 1. Estimate of Scientist Resources



Needed Scientists

Currently there are some 7,064 Scientist-Years located primarily in the land grant universities that sustain the current U.S. food and agricultural system. Critical personnel needs for fulfilling the seven challenges were identified in molecular biology, nutrition and metabolism, engineering, economics, and genetics and breeding. New areas of expertise needed include bioethics, biosystems modeling, logistics and transportation technology, animal behavior, business management, and biomedicine. These needs totaled 5,179 SYs.

Needed Funding

At least $2.1 billion will be needed to support these new scientists. Although these funds would be derived from a variety of sources, a large portion of these resources must come via increased federal investment in base programs of the Land Grant University system.

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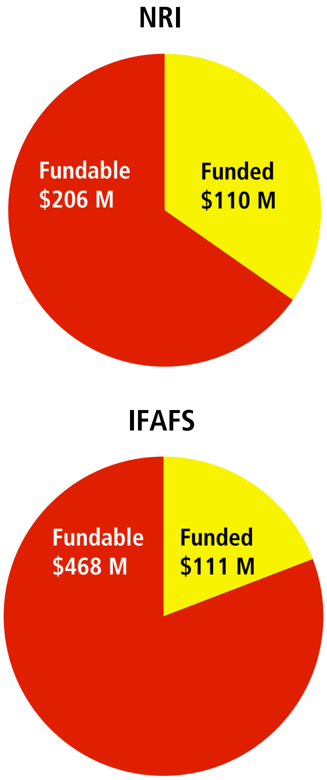
[2] *This summary, supporting data and analyses can be found at www.escop.msstate.edu/draftdoc.htm under "A Science Roadmap for Agriculture"*

[3] *A Scientist-Year (SY) is a full time person working for one year*

Figure 2. Critical Resource Needs in USDA Competitive Grant Programs. Current status of USDA competitive grants program needs. Total of all high quality proposals funded and those that could be supported if additional resources were available.

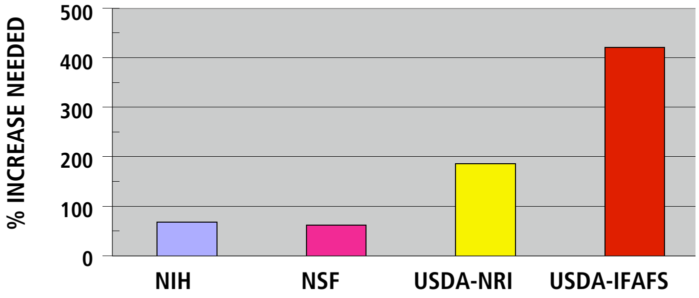


Additional analysis of current funding through competitive grants programs was conducted to see if additional authorities were needed, or if existing programs were simply under funded, *vis-à-vis* the seven challenges of the Science Roadmap. Our analysis revealed that for NIH (non-clinical), NSF, and USDA competitive grant programs there is a critical shortfall of federal investment in high priority research needs (Figures 2 and 3). Even though these programs support some $4.5 billion in competitive research the scientific community currently submits more than $3.5 billion in additional high quality research proposals that would have been supported if funds were available. Moreover within UDSA programs, these shortages are particularly critical. The National Research Initiative (NRI) has the scientific quality capacity to warrant an increase from $110 million to $316 million (a 187% increase). Similarly, The Initiative for Future Agriculture and Food Systems (IFAFS) should increase from $111 million to $579 million (a 421% increase).

Similar data were not available for the Environmental Protection Agency and Department of Energy competitive grant programs. However, it is certain that these agencies also lack resources to support high quality science related to food, agriculture and the environment.

If there is to be a significant increase in the scientific capacity to address the Roadmap's seven challenges, there must be a concomitant and balanced increase in the funds available to support high priority, relevant food and agricultural research. Fundamental to maintaining this balanced portfolio is the need to provide increased base funding to the Land Grant colleges of agriculture.

Figure 3. Comparison of Critical Resource Needs of Several Competitive Grants Programs. Increases (%) in resources required to fund all high quality and meritorious proposals currently submitted.



GETTING RESULTS OUT OF THE LAB

To assure that the fruits of these research investments are realized there will be a need for concomitant investments in technology transfer and adult education. The State Agricultural Experiment Station System's traditional partner in making science accessible to the public is the Cooperative Extension Service. Experience has shown that equal portions of investments are a successful formula for the food and agriculture system.

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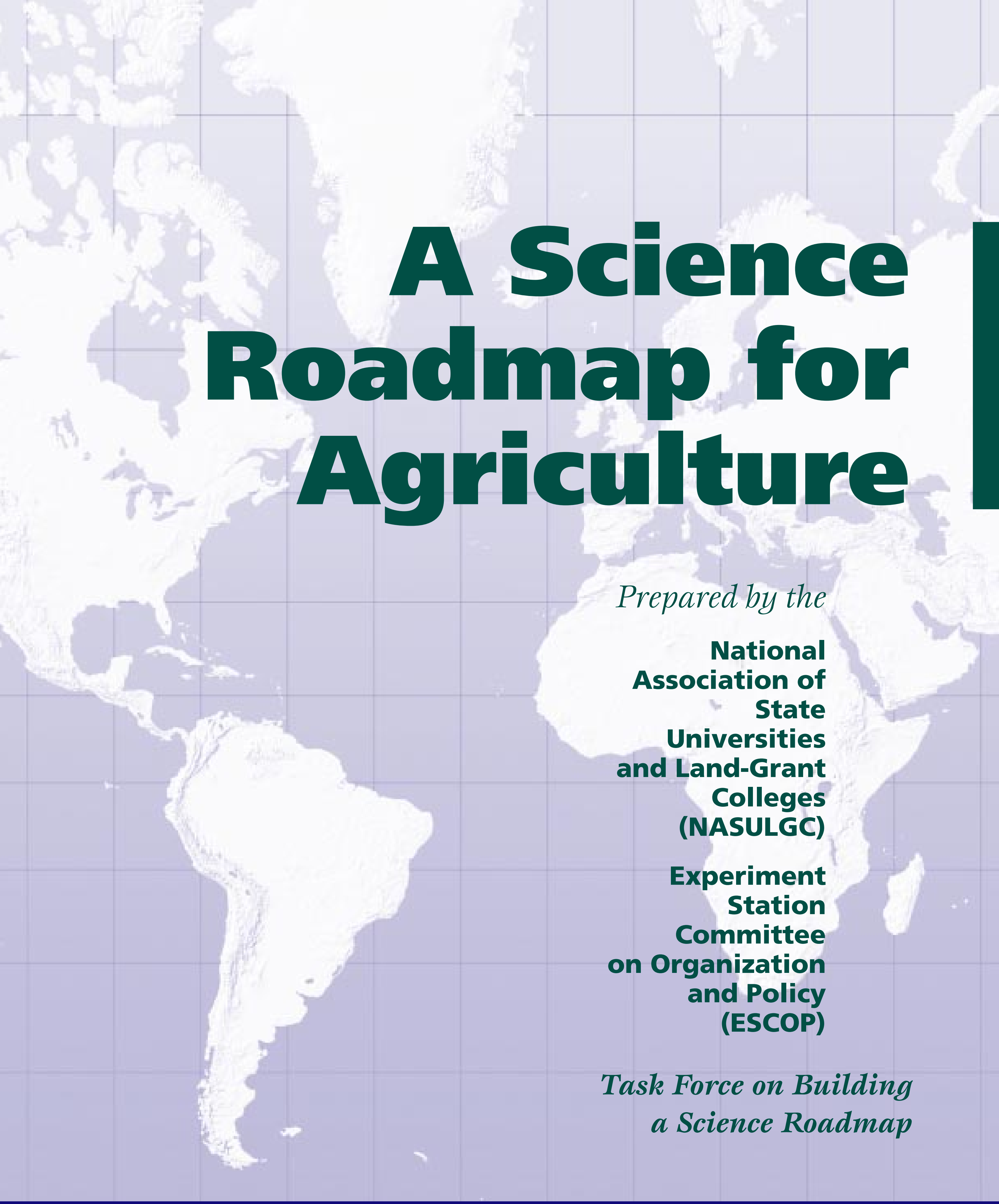

A Science Roadmap for Agriculture

Prepared by the

National Association of State Universities and Land-Grant Colleges (NASULGC)

Experiment Station Committee on Organization and Policy (ESCOP)

Task Force on Building a Science Roadmap

A Science Roadmap for Agriculture

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Preamble

Occasionally one gets to work on a project that can be seen to really make a difference. I want to thank the many faculty members who donated their time and energy to this endeavor, and the Executive Directors of the SAES regional associations who devoted many hours to see its completion.

I also want to thank the State Agricultural Experiment Station (SAES) community for entrusting us with this important task. As you will see, the implications for our next decades are significant.

Within the document, there are inconsistencies that reflect the normal process of scientific endeavors. We are not offering the solutions but a roadmap that describes where we need to go, and not all of the roads are complete.

Our next step as an SAES community will be to tabulate the current investments that are being made in the roadmap's seven challenge areas. Based on this benchmark information it will be necessary to project the scientific capacity that will be needed to achieve the objectives we have set out. Required funding will then have to be calculated and obtained to redirect or hire and support those needed scientific capacities. Finally, a plan for advocating the roadmap's needs to national and state leaders will have to be developed and executed.

I also wish to thank our professional editor, Jennifer MacIsaac, and Cheryl Fields and Barbara Cummings at NASULGC for facilitating publication of this report.

Again, I offer my most sincere appreciation to all of the Task Force members. This endeavor will make a difference.

COLIN KALTENBACH, *Chair*
Science Roadmap Task Force
November 11, 2001

Foreword

Many of this nation's scientific leaders are looking for ways to be more responsive in this time of performance and results planning and reporting. As we enter this new age of accountability, we are mindful that new procedures are necessary for supporting those activities that are scientifically sound, relevant, and responsive to stakeholder needs. Great efforts are being made by public and private institutions to listen to their stakeholders. Additionally, performance planning by research managers based on analytical assessments of the importance of issues and problems are being translated into priorities for resource allocations. Missing from many such priority-setting activities is an assessment of just where science is going, what the active scientific research community thinks will be feasible, and what is beyond our reach.

This agricultural science roadmap represents a major step forward in determining the scientific feasibility of fulfilling stakeholder-identified needs. Armed with an understanding of what stakeholders are requesting, and with a sense of the importance of certain types of problems and issues, the Science Roadmap Task Force has mapped the terrain we feel we can successfully negotiate. In addition, the task force has spelled out what can be done for our stakeholders as specific research objectives that we can meet.

I am very grateful to the Task Force members for their many contributions, and I recommend consideration of these assessments to the rest of the agricultural research management community.

MORTIMER NEUFVILLE
Vice President, NASULGC
November 11, 2001

Introduction

Any 20-year retrospective study of agricultural science and the resulting technologies deployed in agriculture[1] would point to many very significant research accomplishments. There have been substantial improvements in production agriculture, including better methods for assuring crop and livestock health. We have improved technologies to assure a safe, affordable, accessible, and nutritious food supply as well as an efficient, affordable, and dependable fiber supply. We have implemented more environmentally friendly ranching, fishing, forestry, and farming practices. And we have contributed to making rural communities more economically viable. These are some of the positive impacts agricultural science has had on our economy, our society, our environment, and our health.

Although many of these science-driven changes have been positive, other changes have had attendant negative (or even unintended) consequences. Policy makers have expressed an interest in more carefully plotting the future research opportunities of science-for-agriculture, with a view to more carefully deciding research directions and institutional investments, especially when developing goods and services using public funds.

To undertake this assignment, a committee of scholars (see Appendix 1 for the membership) was charged by the Experiment Station Committee on Organization and Policy (ESCOP) to look forward 10 to 20 years to chart the major directions of agricultural science. They were asked to look at the opportunities to enact positive change and help to set a course of research activity that would better serve the needs of our stakeholders. The resulting science roadmap would then assist decision-makers and advocates for the research and education system as they mobilize and plan the allocation of resources for future program areas.

We recognize that many other notable agricultural research budget advocacy activities are currently under way nationally to define the needs of agriculture and the future directions of agricultural science. We have examined the documents generated by the primary advocacy activities, including the Food and Society themes of the Initiative of the National Association of State Universities and Land-Grant Colleges (NASULGC) and the five 2003 budget white papers of the USDA's Cooperative State Research, Education, and Extension Service (CSREES). We also have listened to the plans of the

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[1] The term "agriculture" used herein is intended to include all forms of crop and animal production systems, processing, and marketing and is considered synonymous with terms such as farming and ranching and other forms of food, feed, fiber, and ornamental production, processing, and consumption. It is not intended to exclude any commercial animal or plant agricultural activity. However, we have not given direct attention to forestry or fisheries as food and fiber enterprises. These topics seem worthy of additional roadmapping.

National C-FAR leadership regarding their programmatic intentions. In all instances, we are both congruent and compatible with these initiatives. In fact, it is our intention to be completely supportive of these activities while providing a longer-term look at the potential of scientific research to address those priorities.

In addressing our assignment, we have taken a comprehensive look at agricultural sciences to include technology and engineering sciences. Much of what we will need to do in the next decades will be applying what we already know. In other cases, completely new approaches based on new knowledge will be needed.

In addition, we recognize that as we plan future directions in agricultural sciences, we must recognize that the Land-Grant University model that combines teaching, extension, and research remains fundamental to our success. Therefore, we must plan and implement whatever roadmap decisions we arrive at in collaboration with our counterpart functions.

This roadmap is not a comprehensive description of everything that needs to be accomplished in agricultural research in the next 10 to 20 years. Much of the current agricultural research agenda must be continued into the future. In addition, maintenance research must be sustained to protect past gains, and basic research must be supported if agriculture is to be well served by science. With that understanding, this study looks at what could be accomplished if new investments enable U. S. agriculture to:

- Take advantage of emerging basic scientific discoveries and new technologies;
- Respond to the globalization of markets;
- Contribute to the strengthening of rural, peri-urban, and urban families and communities; and,
- Participate in the protection of the environment and the preservation of natural resources.

This report synthesizes the predictions and recommendations of the Task Force.

CONCEPTUAL FRAMEWORK

The Task Force developed a conceptual framework consisting of the following seven surface features (i.e., needs) of the terrain we are mapping:

- The need to be competitive in a global economy;
- The need to add value to our future harvests;
- The need to adjust agriculture to a changing climate;
- The need to be good stewards of the environment and natural resources;

- The need to make our agricultural enterprises profitable;
- The need to make our families and communities strong; and,
- The need to modify our foods for improved health and safety.

THE SEVEN CHALLENGES

The following seven challenge statements were used to organize the study's activities, and they were subsequently used to report the group's findings. Additional follow-up activities will focus on summarizing the findings for broader distribution and more intensive examination of the potential positive and negative consequences that might arise from selecting certain scientific research alternatives. The seven challenge statements were:

Challenge 1. *We can develop new and more competitive crop products and new uses for diverse crops and novel plant species.* These crop products would include pharmaceuticals; designer foods; and plant-based renewable resources for fuels, other sources of energy, building materials, and industrial feedstock. Through increases in production and processing efficiencies, some of these products will replace fossil fuel-based products. In other cases, new niche markets will emerge in response to the availability of these new products. Our areas of scientific focus should be on:

- Improving crop biomass quantities, qualities, and agricultural production efficiencies;
- Conceiving new markets for new plant products and new uses for these crops;
- Developing technologies to improve the processing efficiency of crop bioproducts (e.g., biofuels, pharmaceuticals, functional foods); and,
- Supporting the development of marketing infrastructure for crop bioproducts.

Challenge 2. *We can develop new products and new uses for animals.* These products include but are not limited to value-added products, new uses, new markets, new contents, and better foods. Our areas of scientific focus should be on:

- Improving conventional technologies as well as developing new technologies to improve the efficiency of animal production;
- Enhancing the value of food and other animal products for both the producer and consumer by using conventional and newly developed technologies that are socially and ethically acceptable;
- Developing innovative technologies to reduce the impact of animal agriculture on the environment; and,
- Developing new and enhanced technologies for improved efficiency and welfare of animals that are processed for food.

Challenge 3. *We can lessen the risks of local and global climatic change on food, fiber, and fuel production.* Socioeconomic and biophysical models are needed to better predict the consequences and opportunities related to anticipated global warming. We believe that more research is needed to uncover methods to reduce greenhouse gas emissions and discover whether carbon can be sequestered (held) in significant amounts in forests, farmlands, and grasslands to lessen the consequences of the coming climatic changes. We also believe crops and livestock can be genetically modified and managed to remain productive with the predicted increases in ambient temperatures. We anticipate that the predicted changes in water availability and soil fertility can be accommodated through genetic modification of crops and livestock. Thus, we believe this area of research represents a valuable opportunity to ease the predicted consequence of greenhouse gases on our food and fiber supplies. Our areas of scientific focus should be on:

- Diminishing the rate of long-term global climatic change by increasing the storage of carbon and nitrogen in soil, plants, and plant products;
- Minimizing the effects of long-term global climatic changes on production of crops and livestock;
- Integrating long-term weather forecasting, market infrastructures, and cropping, and livestock management systems to rapidly optimize domestic food, fiber, and fuel production in response to global climatic changes; and,
- Creating broad-based, comprehensive models to assess the socioeconomic impacts, risks, and opportunities associated with global climate change and extreme climate events on agriculture.

Challenge 4. *We can provide the information and knowledge needed to further improve environmental stewardship.* This can be done through new agricultural practices while continuing to enhance the quantity and quality of food and fiber production through genetics. Our nation's dependence on natural resources and a clean environment mandates attention to preserving soil, air, and water quality. Moreover, the values placed by society on open spaces and ecosystem services—including the conservation of biodiversity—need to be assured. We need to move as a nation toward new policies and programs that protect and preserve both the natural resource base and the environment. Our areas of scientific focus should be on:

- Developing better methods to protect the environment both on and beyond the farm from any negative impacts of agriculture through optimum use of cropping systems including agroforestry, phytoremediation, and site-specific management;
- Decreasing our dependence on chemicals with harmful effects to people and the environment by optimizing their use in effective crop, weed, pest, and pathogen management strategies;
- Finding alternative uses for the wastes generated by agriculture; and,
- Developing better economic models and incentives to assure that environmental stewardship is encouraged.

Challenge 5. *We can improve the economic return to agricultural producers.* This can be done through the development of new knowledge and technologies that improve harvest quality and quantity, product differentiation and diversification (with opportunities for specialization), and enhanced market competitiveness (both domestically and internationally) while reaping the benefits of the emerging 21st century's bio-based economy. Our areas of scientific focus should be on:

- Designing improved decision support systems for risk-based management farming (giving full consideration to small-, medium- and large-scale enterprises);
- Developing sustainable production systems that are profitable and protective of the environment, including ways to optimize the integration of crop and livestock production systems;
- Developing better understanding of how local, regional, national, and global food economies affect the economic return to agricultural producers in the United States; and,
- Finding ways to improve strategies for community-supported food production systems.

Challenge 6. *We can strengthen our communities and families.* The socioeconomic health in rural, peri-urban, and urban settings can benefit greatly from more research on individual, family, and community economic development, labor utilization strategies, and enhanced understanding of the social dynamics in our communities. Our areas of scientific focus should be on:

- Enhancing the problem-solving capacities of rural communities through leadership development;
- Stimulating entrepreneurship and business development in rural communities and new forms of economic activity built around regional trade associations, rural cooperatives, and local production networks;
- Building coalitions among environmental, labor, and community development groups to facilitate democratic social change to ensure that families have access to food, health care, education, and welfare services; and,
- Determining strategies to enhance the well-being of families and individuals.

Challenge 7. *We can ensure improved food safety and health through agricultural and food systems.* Both malnutrition and obesity are contemporary, widespread problem of U.S. citizens. New foods and better eating practices are two of the known strategies that can be used to address the poor dietary health of much of the U.S. population. Other emerging strategies will need to include: functional foods, nutriceuticals, designer foods, and "pharm foods."[2] Our areas of scientific focus should assure our food safety and health by:

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[2] "Pharm foods" is a term used to depict foods that are designed to deliver pharmaceuticals or drugs.

- Improving the nutritional value of foods;
- Developing technologies to create health-promoting foods;
- Discovering better educational methods to help individuals make informed food choices; and,
- Eliminating food-borne illnesses.

Challenge 1

We can develop new and more competitive crop products and new uses for diverse crops and novel plant species.

BACKGROUND AND RATIONALE

Significant portions of the U.S. agricultural harvest are sold overseas each year as raw commodities. New technologies have the potential to multiply the value of that export many fold. Some research indicates that we sell our harvests in the global marketplace for as little as one-tenth of their eventual value, sacrificing jobs and profits in the exchange.

Meanwhile, the U.S. farm community enjoys record harvests while, at the same time, suffering economic losses. Federal commodity subsidy programs—price supports—are said to be at their political ceilings, exceeding $26 billion in payments in 2000. Indeed, nearly one-half of the U.S. farm income in 2000 was from federal subsidies. Policy makers are looking for effective alternatives, because the present situation is not sustainable. New directions are needed.

The United States currently produces about one-third of the world's manufactured goods and uses about one-fourth of the world's energy. In the process, we have become increasingly dependent on imported fossil fuels for energy and petrochemicals for manufacturing. Given the recent terrorism in the nation, decreased dependency on fossil fuels is becoming essential not only to future economic well-being but also to increased homeland security.

Furthermore, in response to growing public pressures, the nation's forests must increasingly be managed to meet multiple uses, such as recreation and watershed management, that may preclude logging.

Growing demands from the energy, transportation, manufacturing, and construction industries will force all of these sectors to look increasingly to crop biomass as a component in the renewable resources "tool kit." Crop biomass can provide competitive, fiber-based building materials, including raw materials for a new generation of building products, while preserving a larger share of national forests for conservation and recreational uses by citizens.

Research is needed on the efficient production and processing of high-quality crop biomass to provide alternative sources of fuels, fibers, industrial feedstock, new characteristics, and chemicals that are not derived from petrochemicals.

Many agricultural commodities have potential uses as bioplastics, biofuels, and biofibers (i.e., plastic, fuels, and fibers made from living matter), as well as other non-food uses. In the next decades, some of these bio-based products will become necessary replacements for fossil fuels as those supplies become diminished and too costly for their current uses. Additionally, many new bio-based products will be derived from novel plants. Some of these may have uses as functional foods with nutritional benefits and health-promoting properties. Others will be used as industrial feedstock (e.g., biodegradable plastics), lubricants, and in other industrial applications. All of these uses will require new technologies that enhance commercial properties, improve the processing efficiency of harvested agricultural commodities, and support expanded and new market infrastructures.

Industrial processing technologies of agricultural commodities have traditionally relied on physical and chemical methods to remove components or change the physical or inherent characteristics of the product. Today, we are on the threshold of a biological revolution. In the next decades, technology will provide the means to efficiently process many agricultural commodities using bioprocessing systems such as enzymatic conversion, bioextraction, biofiltering, and bioremediation. These technologies will transform the nature of manufacturing in ways not yet fully understood. And we can anticipate that these types of bioprocessing technologies will contribute significantly to new markets for conventional agricultural commodities and new products from novel plant species.

Crop biomass engineering is capable of providing an increasingly larger share of the materials and energy currently provided by the petrochemical industry to produce plastics, specialty chemicals, and the organic building materials currently extracted from timber logging in national forests.[3] The United States must now plan for a transition to a greater use of crop-based renewable resources, especially for those sectors of the economy in the best position to make this transition. The U.S. agricultural sector is ideally positioned to produce the raw materials for these products, which will create new jobs, expand marketing opportunities, and provide better profits for U.S. agricultural enterprises and related businesses.

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[3] The United States is already making use of ethanol from crop biomass as a fuel additive and has been turning increasingly to plant biomass for production of construction materials such as framing lumber and straw board. Through biotechnology, plants have been developed in the laboratory to produce biodegradable plastic, feedstock for new types of polyurethane, nylon with stronger and more flexible fibers, and biodegradable lubricants.

U. S. agriculture has made great strides in the development of farming systems that protect air, water, and soil resources; retain and hold carbon in the soil; and reduce our dependency on pesticides. But any significant shift toward the production and harvest of crop biomass for the energy, manufacturing, and building sectors of the economy will require more technological advances in methods that simultaneously keep these crops productive and healthy while protecting the environment and natural resources (see Challenge 4).

Many excellent ideas and products never succeed in the marketplace. This is due not only to inadequate marketing systems and strategies but also to an inadequate investigation into the future social, economic, ethical, and environmental implications related to the consequences of creating those products. The development of sustained and productive markets for new bioproducts will require significant investment into social market research prior to product development.

Once these dynamics are properly assessed and incorporated, access to and investment in transportation and advertisement infrastructure will be essential to product marketability. In addition, the development of a significant technical information base for use by producers, shippers, exporters, rural communities, government agencies, and universities for informed decision-making will be crucial to their success. This information resource must include data and models on social and environmental consequences, suitable production areas, production potential and variability, market potential, geographic dynamics, transportation, processing costs, pricing limits, and global regulatory constraints. The acquisition and development of this information base will necessarily precede the development of a more formal marketing infrastructure, but it will be a critical component of the future research infrastructure and institutional decision-making that has the greatest potential to contribute to the profitability of U.S. agriculture.

Creation and maintenance of such an information resource is appropriately within the domain of universities and government agencies, and it will require state and federal investments. However, much of the coordinated development of the marketing infrastructure will rely on private investment or public-private partnerships and will require active involvement of agricultural producers, commodity groups, and public acceptance. Financial support that recognizes and manages the risks associated with the creation and development of new markets is likely to be a central component in the successful development of marketing infrastructures for crop bioproducts.

The challenge, then, is to move research activities forward in the most promising areas in ways that optimize economic, social, health, and environmental benefits with market development. This will require research investments in biophysical, social, and economic research that builds on traditional and non-conventional approaches to problem solving. And it will require new partnerships with the private sector, where most of the implementation of these new technologies will occur.

CONSEQUENCES OF IGNORING THE NEEDS

Without a meaningful contribution from crop-based renewable resources, the bioproducts industry, manufacturing, and building sectors of the U.S. economy will be faced with meeting the market demands for consumable products and construction materials simultaneously with increasing restrictions on or limits to the extraction of natural resources. The absence of any thoughtful commitment to the development of sound agricultural production and marketing infrastructure could represent a significant impediment to the economic success of new crop products and could potentially lead to increased destruction of soil and water resources and degradation of the environment.

Additionally, we can speculate that if current trends are not reversed, significant commodity markets at home and abroad will be lost to U.S. producers. This expectation reflects higher production costs and stiffer U.S. environmental protection regulations relative to global competition. If we fail to respond, more food, fuel, and fiber will be produced in foreign markets—to the detriment of our farm families, rural communities, the nation's overall economic vitality, and homeland security (see Challenge 6).

SPECIFIC OBJECTIVES OF A NATIONAL RESEARCH PROGRAM

We are proposing that science be used to develop U.S.-produced agricultural commodities through efficient technologies that:

- Expand agricultural market opportunities for U.S. farmers by adding value to raw agricultural harvests;
- Find alternative, renewable replacements for fossil-based industrial materials, fibers, and fuels;
- Design new crops and crop products for emerging markets;
- Provide competitive, crop-based building materials;
- Relieve multiple-use pressures on national forests;
- Develop sustainable practices that provide opportunities to expand the uses of crop-based renewable resources; and,
- Design the framework and provide support for new marketing efforts.

Achieving these objectives will require:

- Social acceptance of continued biotechnology research.
- Increased research into plant and microbial genomics that is combined with plant breeding and uses the latest tools of biotechnology and bioinformatics;
- Accelerated and expanded research into plant biochemistry and genetics to engineer efficient metabolic pathways or value-added traits that meet the quality standards and end-use requirements of materials sought by industry;

- Market infrastructure research aimed at commercially viable bioproducts;
- Improvements in the efficiency of crop biomass production and processing to enhance its competitive advantage relative to using petrochemicals and timber from national forests; and,
- Managing site-specific, within-field, and area-wide variability in yield and quality using precision farming technologies;
- Producing plant biomass with less soil disturbance, either through the use of perennial crops or "no-till" annual crops (crops grown using techniques that reduce or eliminate soil disturbance during planting and cultivating while maintaining crop yield, even in wet years), both to reduce production costs and to limit environmental impacts; and,
- Control pests and diseases, and better manage soil and water resources to assure sustainable productivity.

POTENTIAL IMPACTS OF THE RESEARCH

The time frame for the proposed research may reach two decades. Much will need to be accomplished before many of the envisioned technologies become standard practice. Major commodities have only recently been genetically transformed, and many have not been DNA sequenced for the traits that are likely to be the subjects of this research.

Nevertheless, it can be expected that the following **outputs** would result from this research:

- More efficient bioprocessing technologies;
- Better options for protecting the environment from the effects of bioproduction and bioprocessing; and,
- More choices for adding value to and marketing harvested agricultural products.

Additionally, we can expect the following **outcomes** from investing in bioproduction and bioprocessing technologies:

- More options for farmers for marketing their crops; and,
- New products for consumers.

Finally, the expected **benefits** from successfully accomplishing the vision of this research activity would be:

- Greater farm profitability;
- Economically healthier rural communities; and,
- Reduced reliance on fossil- and petroleum-based resources.

Challenge 2

We can develop new products and new uses for animals.

BACKGROUND AND RATIONALE

In recent years the U.S. livestock industry has undergone a dramatic shift to a more concentrated industry, with an emphasis on maximizing production within minimum space allotments. This trend essentially applies to all animals reared for food production with the exception of open-range beef cattle. In addition, the industry is using many of the by-products of animal production. For example, the pork industry proclaims to use everything but the "oink." Although this is the trend, the value of by-products obtained from processing animals when measured against production costs (particularly for labor and social and environmental consequences) is often marginal. There is a need to re-examine current animal production practices and farming and ranching systems to permit greater economic, social, environmental, and health returns from animal agriculture.

Efficiency: Research must develop new technologies that increase production efficiency. This includes, among other factors, improvement in the yields of:

- Milk produced per unit of feed consumed;
- Muscle produced per unit of feed consumed; and,
- Eggs produced per unit of feed consumed.

At the same time, we also will need to produce leaner animals, improve their reproductive efficiency, and provide greater economic return on producer investments.

If quality can be maintained, technologies that lower the quantity of feed consumed per unit of output will benefit both the producer and the consumer as the cost of feed represents about 70 percent of animal farming expenditures. More efficient feed technologies also provide opportunities to reduce the amount of waste (manure) generated per unit of animal product.

Remarkable advances in biotechnology research during the past 20 years have identified several new technologies that increase the efficiency of feed and animal production. An impressive array of tools (e.g., biochemistry, molecular biology, genomics, bioinformatics, cloning, gene therapy, and genetics) is now available to learn more about the biological and genetic mechanisms that determine how efficiently an animal is produced.

Research emphasis will need to be placed on understanding the underlying biological mechanisms that control growth rate of muscle, fat tissue, daily milk production, reproductive performance, egg production, and digestion, which regulates nutrient use and nutrient loss from the body (and, therefore, contributes to manure management issues). Advances in our understanding of these biological mechanisms will result in the development of new products or strategies that enhance the efficiency of animal production.

Intensification: To increase efficiency, current animal production practices house a large number of animals within a relatively small space. As a result, large amounts of manure are produced on a small amount of land or water. Improperly managed animal production and manure disposal pose a threat to soil, water, and air quality, as well as to human and animal health. A major research effort is needed to develop proper management practices and technologies that reduce the environmental impact of these animal production sites and to develop effective uses for the animal wastes generated. Research in this area should involve various aspects of animal nutrition and proper feeding strategies; manure handling, storage, treatment and land application; animal welfare; rearing unit design and operation; soil treatment and crop production; conservation practices; and environmental impact assessments.

Labor and Welfare Issues: Working in slaughterhouses, flesh-foods processing plants, milk and egg plants, at-sea or shore-side fish processors, and other facilities associated with animal processing is often considered to be undesirable employment. As a consequence, illegal aliens often perform these jobs, which can create various social and legal problems for both workers and employers. In addition, greater interest in worker safety has called the ergonomic conditions found in animal production plants into question, and there are continuing concerns about animal welfare. Animal agriculture has not been on the cutting edge of addressing these social and health issues.

Consumer Issues: The impact of biotechnology on animal agriculture and related food systems largely will be dependent on the extent to which consumers/producers and society as a whole are willing to adopt the products of these technologies. All too often, societal and consumer concerns are dealt with too late in the commercialization process, and the focus of risk assessment does not take into account cultural or societal norms of what is acceptable or unacceptable technology. Resolution of any issues requires the early intervention of socioeconomic sciences.

We appreciate that the successful development and adoption of new technologies for animal agriculture will require public acceptance of the social, scientific, economic, and legislative issues associated with these emerging technologies. Thus, we see a need to create a national program designed to generate open public discussion about the issues involved in emerging animal production technologies. The mandate of the proposed program could well be extended to all emerging technologies relevant to agriculture.

Open discussion about the issues surrounding emerging technologies is of paramount importance to ensure that researchers understand the public's concerns about a particular technology, and that those concerns are responsively addressed. Given these considerations—and in addition to research on animals—the scientific community will need to:

- Promote an increased understanding of the scientific bases underlying emerging animal agriculture technologies;
- Assess public opinion as well as the social and economic implications related to adopting emerging animal biotechnologies that affect the future of both society and agriculture;
- Foster an increased understanding of the benefits and risks associated with adopting emerging animal agricultural technologies and determine under what circumstances societies are willing to accept those risks;
- Inform and educate developers of new technologies about public attitudes and the implications of those attitudes as they relate to technological change in the food system and agriculture; and,
- Facilitate active communication among scientists, science administrators, policymakers, consumers, and producers to ensure that all viewpoints contribute to the safe and effective development and adoption of socially acceptable agricultural biotechnologies.

CONSEQUENCES OF IGNORING THE NEEDS

As the livestock industry continues to develop larger and more concentrated production units, the general public has become increasingly resistant to allowing these production units to be built in their communities. The result is escalating attempts to pass local, state, and national regulations to regulate and/or prohibit the development of these units. These concerns are fueled by periodic accidents and environmental abuses associated with a limited number of these large production units.

The livestock industry has developed large production units based primarily on the economic benefits and with too little regard to their environmental impact or assessment of the risks to the general public living in the surrounding areas. Some of the early research efforts aided in the development of these production-intensive units, but more recently, public-sector research has been trying to 'catch up' with the industry, addressing crises only when they develop. Thus, a major, high-priority national effort is necessary to address this increasingly serious problem. If such an effort is delayed, social and regulatory pressures may drive a significant portion of the food-animal industry off shore.

We are as a nation transitioning into a technological era where new, basic discoveries offer unprecedented ways to enhance food production efficiency. Further, a substantial amount of scientific information already is available to form the basis of a major research effort to reduce the environmental impact of animal agriculture. For example, research already demonstrates that many swine producers are feeding excessive amounts of nutrients to their production animals. Properly disseminated, that knowledge has excellent potential to reduce nutrient excretion by swine and the subsequent negative impact on the environment. Similar research findings indicate that changes in management practices related to production of other livestock also can be effective in reducing the amount of nutrients excreted.

To both maintain our high standard of living and our ability to supply these products, animal agriculture must continue to improve both its offerings and its methods of producing those offerings. Even if per capita consumption of total animal product decreases, without continued improvement in technologies, changes in practices, and growth in markets, the United States stands to suffer from the failure of an important component of its agricultural sector.

SPECIFIC OBJECTIVES OF A NATIONAL RESEARCH PROGRAM

A broad portfolio of research projects is necessary to meet the future needs of animal agriculture. Beyond biophysical research, research activities will need to be integrated with the needs and desires of the public. We must involve the industry's research community and a broad base of stakeholders in planning priorities. This activity should include consumers, the retail sector, and less directly involved groups (such as those concerned for the environment) in order to develop a common agenda that best serves the entire nation.

Major investments are needed in animal agriculture technologies that improve the efficiency of animal production and processing; find expanded, new and/or novel markets for animal products; and develop value-added animal products for domestic and foreign markets. In addition, greater efforts are needed to mitigate and/or avoid the environmental impacts of intensifying animal-production plans.

Specific objectives are:

- Close current science "gaps" in animal agriculture through expanded programs in functional genomics, proteomics, and bioinformatics;
- Develop more efficient procedures for utilization and preservation of germ plasm;
- Create value-added products that are more efficiently produced and meet health, safety, animal welfare, and consumer-acceptability standards that are significantly higher than those of today through:
    - Technologies to improve raw material quality;
    - Newer, higher-value uses for animal products; and,
    - Increases in the value obtained by the food system for the total utilization of animal products.[4]

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[4] This will include meeting consumer needs for meat, dairy, egg, and products from these raw commodities that meet organic, natural, low-salt, low-fat, kosher, halal, specific ethnic group needs, and other special dietary needs.

- Develop new and familiar species through both biotechnology and classical breeding that truly reflect corporate, societal, and individual needs;
- Improve knowledge of animal behavior and develop management practices that enhance animal well-being;
- Generate more humane and less stressful animal handling systems from farm to slaughter, including:
  - Improved slaughter systems;
  - More ergonomically sound procedures for handling animals post-slaughter; and,
  - More use of robotic systems and supporting computer systems to replace human labor, particularly in the least desirable jobs.
- Increase research to uncover methods to more effectively communicate the contributions of animal agriculture and animal products to the well-being of people around the world;
- Conduct policy and technical research to address the environmental and social impacts of animal agriculture including:
  - Better land and water use regulations;
  - Better manure management practices;
  - More appropriate animal-feeding methods including:
    - Use of more plant-based by-products;
    - Use of fewer "human-equivalent" grains;
  - Improved animal welfare requirements;
  - Improved work conditions;
  - Reduced human labor requirements; and
  - Fair marketing practices.
- Develop cost-effective methods to increase food safety; and,
- Create systems that minimize cross-contamination of pathogens from one animal to another, including new methods of control and improved natural resistance to diseases.

We foresee the need to develop a scientific database of cost-effective management practices, technologies, and decision aids to sustain the development of the food animal industry without degrading environmental quality, posing a threat to human and animal health, or disregarding societal concerns. The major components of this information resource should include but not be limited to nutrient management,[5] atmospheric emissions, pathogens, and pharmaceutically active compounds.

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[5] To illustrate this point, a Cornell University-developed computer model, referred to as the Cornell University Nutrient Management Planning System (CUNMPS), integrates research knowledge and production experience about livestock nutrition, crop requirements, and manure management. The software is used to determine the amount of manure nutrients that can be recycled on crops, and where and when to apply them to protect water quality. In a case study involving four dairy farms, CUNMPS, matched with a herd nutrition-optimizing component of another computer program, showed that nitrogen and phosphorus in manure can be reduced by up to one-third, while feed costs can be reduced by $50 to $130 per cow annually.

POTENTIAL IMPACTS OF THE RESEARCH

An ideal animal agricultural production system would:

- Be socially and ethically accepted;
- Produce healthy, tasty, safe, high-quality foods for consumers;
- Have minimal impact on the environment;
- Provide quality jobs for the work force; and,
- Return an equitable financial profit to its producers and processors.

In return, consumers would both use the products and understand and comfortably support this industry.

Maximizing nutrient retention by the animal will facilitate more efficient conversion of feed ingredients to meat, egg, and milk products while reducing the amount of manure produced and lowering the content of certain nutrients in the manure. Development of manure disposal and utilization practices and technologies in an environment-friendly manner will benefit both the food animal industry and the general public. New management practices and treatment technologies will be developed to reduce atmospheric emissions and ground water contamination, as well as inactivate pathogens and pharmaceuticals, which should help to regain public confidence in the industry.

An expected **output** from a national research plan for animal agriculture would be:

- New knowledge and products, such as highly sophisticated computer programs to model the various aspects of animal nutrition; and,
- New production and manure management techniques—from nursery to market stages of production—for each food-animal species.

Expected **outcomes** and **benefits** from this national research effort may include, but should not be limited to:

- A sustainable food animal industry;
- A marked reduction in the environmental impact of the livestock industry; and,
- Greater public confidence in the industry.

Challenge 3

We can lessen the risks of local and global climatic change on food, fiber, and fuel production.

BACKGROUND AND RATIONALE

During the next 20 years, climate variability caused by atmospheric increases in greenhouse gases is expected to become a major global concern.[6] These predicted climate changes would likely be expressed as increased global temperatures and greater frequency in climate extremes.

Since agriculture requires major land and water resources, any long-term changes in climate conditions may have profound effects on crop and livestock production. Predictions of future increases in the earth's temperature and changing precipitation patterns suggest adverse effects on agriculture for many parts of the world.

Recent increases in the earth's near-surface air temperature as well as the temperature of the ocean are well documented, and they are correlated with human activities. Although local impacts of global warming are difficult to predict, the scientific consensus is that shifts in average and seasonal air temperatures, as well as the total and seasonal distribution of rainfall, will disturb both natural and agricultural ecosystems. It is expected that the temperature of the earth's surface may rise as much as 1.5 to 4.5° C over the next 100 years, primarily due to increases in greenhouse gases. The physical and ecological effects of these changes are expected to result in significant consequences for agriculture.

Global climate change also poses risks to the world's ecosystems and human populations, but these risks are, for the present, difficult to identify or quantify with certainty. Current models suggest that it is the intertropical regions that will suffer the most negative effects

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[6] Greenhouse gases include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), water vapor (H_2O), ozone (O_3), and the chlorofluorocarbons (CFCs, including CFC-12 (CCl_2F_2) and CFC-11 (CCl_3F)). Because these gas molecules absorb infrared radiation, the temperature of the earth is dependent on their concentrations in the atmosphere. Release of these gases to the atmosphere has been escalated by the burning of fossil fuels, agricultural tillage practices and fertilization of the soil, deforestation, and by other human activities.

in terms of agricultural production.[7] Northern and southern latitudes may see an increase in agricultural productivity as a result of longer warm seasons, increases of atmospheric carbon dioxide levels, and increased precipitation. However, season-to-season variability and extremes in weather-related events are likely to increase in most parts of the world, with more flooding and more intense drought years. It also is likely that a rising sea level—as well as rising lake, river, and reservoir levels—will have significant negative impacts where many people live, work and produce crops.

Rain-fed crop acreage is expected to decline dramatically in the face of climate change, while irrigated-land acreage should increase modestly in areas where water will become more readily available and affordable (Adams et al., 1990). World cereal production is expected to show a slight-to-moderate decline even with the benefits of elevated carbon dioxide levels and expected changes in production practices (Rosenzweig and Parry, 1994).

A growing body of information now is available on the economic impact of climate change on crop and livestock production in the United States. Although expert opinions are by no means unanimous (Nordhaus, 1994), new research suggests that the economic impacts of climate change could actually exceed those due to population growth (Gleick, 2000). Damage to global water resources alone is predicted to exceed $21 billion annually, with a majority of those costs associated with controlling water pollution (Titus, 1992). However, these estimates do represent considerable uncertainty, a realization that has undoubtedly contributed to difficulties in developing tangible, global climate-change policy (e.g., the Kyoto Agreement).

U.S. agriculture could make a vital contribution toward reducing net emissions of greenhouse gases if both the rate and total amount of carbon[8] and nitrogen stored in soils could be increased. The earth's carbon and nitrogen cycles are complicated, but increases in terrestrial carbon and nitrogen over several decades could have a significant impact on reducing the total amount of greenhouse gases in the atmosphere. Storing greater amounts of carbon and nitrogen in soils would help to mitigate the risk of global warming, "buying time" for other carbon-storage technologies to be developed and implemented. Because plants and microorganisms require both carbon and nitrogen to build biomass, management of terrestrial carbon must work hand-in-hand with management of nitrogen.

Carbon also is stored in the tissue of plant roots, below the soil surface, where microbial activity is slower than at the soil surface. Plants that grow for long periods—or accumulate large amounts of biomass (e.g., perennial grasses and trees) have the potential to store substantial amounts of carbon. However, if the tissues of those plants are harvested and preserved in forms that will easily biodegrade (break down in the soil), the

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[7] Many developing countries with already large and increasing populations are located in the intertropical zone. In these areas, agricultural production is faltering due to rapid depletion of land and water resources. Under such circumstances, any adverse long-term climatic changes may result in large-scale food shortages or even widespread famines. This may in turn lead to economic, social, and political instability on a global scale.

[8] Photosynthesis by plants removes carbon dioxide from the atmosphere and converts the carbon to the organic compounds that make up plant tissue.

storage is not permanent. When the plants die, their tissues decompose, returning carbon to the atmosphere in the form of carbon dioxide or methane.

It is possible that long-term increases of carbon dioxide in the atmosphere may have a "fertilizing" effect on plants, promoting their growth and productivity. Unfortunately, the higher air temperatures that are expected from global climate change also are likely to promote greater microbial activity in soils. This greater activity, in turn, increases the rate at which plant tissues decompose and release carbon dioxide back into the atmosphere where it will, again, contribute to the greenhouse effect.

Still, long-term storage of terrestrial carbon can be achieved by adding as much carbon as possible to organic matter in soils and by managing soils and vegetation to reduce the rate at which decomposition occurs. This can be accomplished by:

- Judicious additions of fertilizer nitrogen to stimulate plant biomass accumulation;
- Careful management of the organic matter in annually cropped soils;
- Irrigation strategies that increase biomass accumulation without increasing water pollution rates;
- Growing more perennial crops that produce significant amounts of below-ground root systems; and,
- Converting cropped land to conservation land or wetlands.

In addition to diminishing the rate of climate change, increasing the concentration of organic matter in soils has other important environmental consequences. These include:

- Lessening the potential for soil erosion from farmland;
- Limiting wind erosion from cultivated soils;
- Improving both the permeability and water-holding capacity of soils; and,
- Improving surface water and ground water quality by containing excess agricultural chemicals and trace metals at the site of their application.

Current literature on the issue of climate change suggests that the distribution patterns of U.S. crop and livestock industries also may be negatively affected by long-term global warming. Anticipated instability of commodity prices, declining availability of irrigation water, and loss of biodiversity and genetic resources may drive some of this. In addition, increases in temperature may cause changes in the patterns and intensity of precipitation on a global scale and, consequently, affect where and how commodities can be produced.

Both crop and livestock production in the United States already has shifted to states where climate conditions are more favorable than in others. For example, the four major crops in this country (corn, wheat, soybeans and cotton) now are grown in just four or five states. Similarly, the livestock industry, including beef cattle, dairy, swine, poultry, and fish, is moving toward concentration in just a few states. Further shifts in climate conditions may accelerate this pattern and affect both food and fiber production.

In the United States, the availability of plentiful natural resources (i.e., land and water) and other production inputs (e.g., fertilizers, pesticides, improved seeds, and technical information) has, to a large extent, relieved the adverse affects of climatic variability. However, the situation is changing rapidly now because resources are becoming less plentiful, inputs are becoming more expensive, and the predictions for global warming are becoming increasingly consequential.

Given expectations for significant increases in world demand for food, fiber, and biomass-based energy, new research and improved practices will be needed if reliable agricultural production and food security are to be maintained in the face of climate changes. Among the imperatives will be the overriding need for food and fiber production systems that provide as many alternatives as possible to producers, policy makers, and other decision-makers involved in agricultural-systems management. Other imperatives will be the need to:

- Develop food and feed crops and animal production systems that are resilient to climate variability;
- Improve our abilities for accurate short- and long-term weather forecasting;
- Provide long-term land and water management practices and policies that mitigate the impacts of weather and climate, based on sound scientific information;
- Protect the earth's ecosystems for the benefit of future generations by limiting the effects of global climate change;
- Protect the capacity for food production and distribution for future populations even during periods of climatic and political instability; and,
- Provide the means to stabilize income for agricultural producers even during periods of climatic instability.

Some of the other climate-related concerns that may need to be addressed through research include the:

- Possibility of increased incidence of invasive species of insects and other pests;
- Loss of biodiversity among plants and animals unable to adapt to climate changes; and,
- Economic and social consequences of long-term climatic changes.

To address these complex biophysical, economic, cultural, and social interactions on multiple scales will require new research approaches, including systems science. The systems-science approach uses specific models that define interrelationships and show how the related pieces fit together. These models are useful for understanding how "things work"; as management tools for strategic decision-making in production, processing, marketing, and overall resource management; and as methods for making informed and objective policy and regulatory decisions.

Our efforts will need to strongly encourage a systems-science approach to understanding the complex system we call agriculture. Today, with advances in computer-based technologies, new trade-off models, and opportunities to apply systems science to these complex questions, we can begin to unravel the consequences climate changes will have on agriculture at many levels of scale (farm, community, eco-regional, national, hemispheric, and global). The potential provided by combining simulation and other types of models with expert systems can provide extremely powerful decision-making tools to ensure agricultural stability in the future.

CONSEQUENCES OF IGNORING NEEDS

Each year, the United States is said to be responsible for releasing 25 percent of the world's carbon dioxide. A directed U.S. agricultural research effort could assist our country and others in dealing with the consequences of greenhouse-gas emissions and climate change. However, if the United States and other governments ignore the opportunities to isolate carbon and nitrogen from the atmosphere and forego other means to reduce the release of greenhouse gases, it is likely that global climate change will accelerate, and agricultural production will be impacted.

While climate change may not significantly affect U.S. food security at the national scale in the short term, producers in many local areas will struggle with seasonal uncertainties and extreme weather events. Surface-water quality is likely to degrade as a result of increased erosion of cropland. The quality of surface water also may deteriorate due to an anticipated increase in the use of pesticides to combat insects and diseases that are able to exploit longer—perhaps wetter—growing seasons.

Ignoring the need for research in this area may place the long-term productivity and competitiveness of U.S. agriculture at risk and disrupt the economic well-being of rural communities. Inattention to the challenge also may aggravate contemporary environmental conflicts related to the use of land and water resources.

Agricultural producers, processors, marketers, and policy makers will continue to be faced with difficulties in sustaining long-term productivity and profitability. However, without the benefit of science-based information that assesses the short- and long-term risks and consequences of significant change in global climate, poor decisions will be made in business, finance, policy, and regulation.

SPECIFIC OBJECTIVES OF A NATIONAL RESEARCH PROGRAM

The overall aims of this effort should be both to improve agro-economic models designed to optimize domestic food, fiber, and fuel production in response to changing global climate over a 50-year time frame. To address the short- and long- term consequences of global climate change on agriculture, some specific research objectives must be achieved. We will need to:

- Develop accurate mathematical models for assessing the short- and long-term effects of both man-made and naturally caused climate changes on crop and livestock;[9]
- Use new mathematical modeling methods, including artificial intelligence, to develop accurate and reliable models to aid decision-making at all levels of agricultural operations;
- Incorporate into simulation models and expert systems the vast amount of useful information and concepts generated by basic, strategic, and applied research in agriculture and other sciences, and capture the practical experiences of successful operators in a form that can be used by others in decision-making;
- Invest in fundamental research including, but not limited to:
    - Understanding the interactions between plants and microbes that are critical to using technological advances in both biomass production in crops and organic matter stabilization in soils;
    - Optimize nutrient and water uptake by plants to encourage growth and carbon storage, which is essential for maximizing biomass accumulation in crops;
    - Determine if adding materials such as clay to soil organic matter will slow its decomposition for decades or even millennia.
- Link the simulation models of different scales of agricultural and ecological systems so that the behavior of all agroecosystems can be better understood and more accurately predicted;
- Predict the effects of decreasing availability of water on future land-use patterns and distribution of crops and livestock;
- Employ current and evolving technologies and develop new food systems that can benefit from the impacts climate changes will have on crops and livestock;
- Develop:
    - Stress-resistant crops and livestock;
    - Adaptive farming systems and "Best Management Practices" for changing environmental conditions;
    - Risk-management strategies to mitigate unfavorable shifts in climate;
    - Soil and crop management decision-support systems that track how both economic and biophysical variables interact;
    - Strategies to prevent losses in biodiversity and genetic resources that may result from adverse climate conditions; and,
    - Stronger outreach and educational programs to inform the public about options and alternatives.

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[9] What is needed are accurate, long-term climate models for the meso- to global-scales, including novel approaches to describe climate variability, possibly using fuzzy sets and neural networks.

- Improve basic knowledge of carbon and nitrogen dynamics at both the field and watershed scales;
- Investigate:
  - New crops and bio-based production systems that accumulate biomass;
  - New techniques to accurately predict the impact of soil and crop management technologies on soil characteristics (such as organic matter content) at the watershed scale;
  - New technologies for conservation tillage (also known as "no-till");
  - New agricultural and industrial uses for grass- and wood-based products so that the carbon in those grass and trees will be stored for longer periods;[10]
  - New ways to reclaim currently unproductive lands (for example, highly eroded and salt-affected soils) so that they can be used to grow biomass-accumulating crops, such as grasses and trees;
  - The use of soil amendments that would retard natural rates of organic matter decomposition without compromising crop production in succeeding years.
- Quantify the linkages and relationships of economic components from different scales (e.g., macro-economy vs. microeconomy, or crop field vs. agricultural ecosystem);
- As related to climate change, trace the impact of agriculture and other economic activities in rural areas on the well-being and quality of life for communities;
- Analyze the economic and social impacts of alternative farm policies and regulations on consumer prices, reasonable farm income, environmental concerns, viable communities, and global weather variability and change;
- As affected by the anticipated climate change, analyze relationships among the general economy, agriculture, communities, and families; and,
- Conduct the essential biophysical and economic research to establish critical interrelationships between the biological and economic functions that are vital to the success of agriculture and the consequences of climate change.

Perhaps the most urgent need is to develop new institutions that allow scientists and policy makers to work together closely to design and implement flexible agricultural and environmental policies for land use and crop production.

POTENTIAL IMPACTS OF THE RESEARCH

Global climate change has the potential to dramatically alter agricultural systems on a time scale that is vastly different from historical rates of social and institutional change. The issue alone will require significantly more research and dedication of resources than has been available in the past. The information and comprehensive models resulting from

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[10] Improved bioproducts that are competitive with similar products made from fossil fuels will decrease reliance on fossil fuels and encourage producers to dedicate land to crops that increase below-ground carbon and nitrogen storage. An important part of this strategy would be to improve processing technologies that convert the raw crop to a usable product.

this work will be critical to decision-makers, policy analysts, natural resource managers, the entire agricultural community, and all societies in general.

The primary goal of land management strategies must be to minimize losses of carbon and nitrogen to the atmosphere, to surface and ground water, and to the ocean. If successful, the long-term rate of climate change due to global warming may slow, and future generations will have a better chance to adapt to the ecological, social, and political consequences that will occur.

Research on long-term effects of change in climate conditions will have a direct impact on the production of food, fuel, and fiber and also on the stability and security of agricultural commodities worldwide. Since substantial increases in world food production will be needed to keep pace with rapidly increasing population growth, research in this area is essential to help produce globally-sufficient quantities of food for coming decades.

A number of secondary benefits will accrue from the improved understanding of the fundamental mechanisms of terrestrial carbon storage. With successful implementation of the envisioned technologies, we will see the emergence of many biomass-based products, improved water quality and sediment control (because of less erosion), and improved habitat for wildlife.

Systems-science knowledge will assist in predicting, mitigating, and adapting to global climate change and climate variability. Research will result in better policy, more informed decision-making, better use of natural resources, and improved efficiency of food, fiber, and forest production, all operated through management systems compatible with economic, social, and environmental values.

Challenge 4

We can provide the information and knowledge needed to further improve environmental stewardship.

BACKGROUND AND RATIONALE

For much of the 20th century, U.S. agricultural research was focused on increasing production of food, feed, and fiber. That intense focus tended to ignore the impact of production decisions on ecosystem balance. In the coming 20 years, it is imperative that scientific research lead agricultural landowners and producers toward a new standard that values not only the food, fiber, and fuel products of agriculture, but also the ecosystem goods and services that agricultural-land management can provide. Today—because an abundant national food supply is assured in the short term—these services are not challenged and have become highly valued by the U.S. society at large. However, to enhance the long-term sustainability of U.S. agriculture for the 21st century, research emphasis on ecosystem goods and services will be critical. If this effort is not pursued, some of these services may be lost when choices have to be made.

Current agricultural management of land resources, as well as the management of domesticated plants and animals, creates ecosystems in which biological, chemical, and physical processes interact intensely with one another. The similarities and the relationships of agricultural ecosystems (i.e., agroecosystems) to natural, less-managed ecosystems are significant. In all cases, the balance and accounting of inputs and outputs of materials and energy are critical to assessing the overall resilience of the ecosystem to change. Agricultural producers use inputs such as nutrients, antibiotics, pesticides, and water.

The management of agroecosystems in the United States impacts not only food production but also wetland and estuary systems, soil quality, surface and ground water quality, wildlife habitat, carbon storage in soils and vegetation, and greenhouse gas emissions, among other things. Management of such complex, interacting processes demands a "systems" approach that has been described elsewhere in this document (see Challenge

3). The current national interest in "precision farming" is centered on technologies that allow producers to monitor, adjust, and measure the inputs and outputs of agricultural production (i.e., seeds, fertilizers, pesticides, labor hours, crop yield) as they relate to a single field or production area. The agroecosystem model demands that management of large-scale units (i.e., whole watersheds) receive comparably intense research attention.

Fortunately, researchers in traditional crop-production agriculture have an outstanding model to follow in agroecosystems research—the forestry model. Nationwide, forestry researchers have long integrated natural resource inventories, multiple-use management of resources, integration of wild and domestic species, concerns about maintaining biodiversity, integrated pest management, and wetland management into timber production practices. Current forestry research demonstrates that planting or maintaining buffer strips of land near streams will trap excess agricultural chemicals and provide timber and wildlife habitat. This work is an excellent example of the positive impact agroecosystem concepts can have on land management and water quality.

Bioproducts derived from both woody and herbaceous species are likely to become more competitive with petroleum products in coming years, and their production will be enhanced if there is a strong research base that shows producers how to incorporate these crops into traditional farming practices. These are just two examples of the types of research that can benefit from close collaboration between foresters and more traditional crop and soil scientists.

Scientific research can and should lead the way toward a new appreciation of the societal goods and services that agroecosystems provide in addition to food, fiber, and fuel. But incentives for landowners and producers to improve the management of complete agroecosystems (as opposed to simply "fields" or "farms") must come from the larger society. The critical need to integrate research and agricultural policy (and regulation) opens up a redefining, new role for agricultural extension efforts at Land-Grant Universities.

Sustainable agricultural production is reliant on the protection and preservation of the natural resources base that supports its existence. The quality, quantity, and accessibility of soil, water, air, and biotic resources determine the success or failure of food production and security. Therefore, care must be given to assuring that agricultural production practices do not add to pollution or degrade natural resources.

During the next 25 years, world population is expected to increase by about 2.5 billion people, mostly in the economically developing world. Despite expectations for major increased demand for food, annual rates of yield increases are not keeping pace with population growth, and the options are limited to fill this emerging gap. Clearly, the deficit must be met primarily from increased productivity on land already under cultivation. Under these circumstances, water quality and availability will become the greatest challenge to be faced.

Today, agricultural production uses about 70 percent of water that is currently available. At the same time, urban communities continue to demand a larger share. With rivers drying up, wetlands diminishing, and major ground water aquifers being depleted at unprecedented rates, we are moving toward significant scarcity of water resources. The result is that the projected need to double food production "must largely take place on the same land area and using less water."[11]

Obviously, trade-offs have been made in managing the natural resources that support agriculture. Unfortunately, most of these trade-off relationships are too poorly understood to effectively plan future policy and properly allocate scarce human and financial resources. Some clear choices will need to be made. These will necessarily involve:

- More environmentally friendly crop and livestock health protection strategies;
- More scientifically sound natural-resource preservation strategies;
- Better environmental pollution prevention and management schemes;
- Greater dependence on science-based environmental regulations;
- More technology-based waste management solutions; and,
- New natural-resource management technologies that provide multiple options for farmers, foresters, fishers, and ranchers.

More Environmentally Friendly Crop and Livestock Health Protection Strategies: Conventional approaches to the management of pests and diseases that affect crops and livestock have relied primarily on combinations of strategies, often integrated in ways to produce effectiveness that is beyond simple additive effects. Known as "integrated pest management" (IPM), these methods have relied on chemicals or drugs to control pests. Although safety assurances have been provided for all of these products, concerns remain in the minds of many consumers about the potential risks associated with these treatments. Much of this concern is focused on environmental and public health consequences.

New opportunities have begun to emerge from genomics research that hint that more biologically based solutions to long-standing pest and disease problems in crop and livestock production may be possible. Questions are being asked about the universality of pathogenesis mechanisms—the natural abilities that allow plants and animals to fight off pests. In addition, commonalities are being found in the biochemistry and genetics of pest resistance across a broad array of organisms. Information from DNA sequencing has suggested that these functions are more similar in different organisms than previously thought and that common research strategies may provide clues to new approaches to plant and animal health objectives.

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[11] The extent of global crop damage from pests and pathogens is substantial, with up to 40 percent of plant productivity forfeited in Africa and Asia each year, and about 20 percent in the economically developed world. Much of this damage occurs after the crops are fully grown. Thus, reducing the damaging effects of pests and pathogen on crop products is equivalent to creating more land and more water.

The notion here is to replace today's chemically based plant and animal health strategies with more comprehensively organized biotechnologies. This approach would provide a scientifically sound and logical bridge between existing but independent plant and animal research activities, resulting in new and novel disease and pest treatments for crops and livestock—strategies that could be much more environmentally friendly.

In a related way, there needs to be more research focused on the possibility that exotic and invasive species of weeds, pathogens, and pests could be introduced into the country. Heretofore, little research attention has been given to quarantine and eradication strategies despite the fact that substantial harm could result if certain agents were to enter the United States. In addition, should enemies of the nation target agriculture for bioterrorism—a possibility that recently has gained broad public attention—we would find ourselves highly vulnerable. Better detection systems, programs for remediation, and intervention strategies are needed for accidental, intentional, or terroristic introductions.

More Scientifically Sound Natural Resource Preservation Strategies: The utilization of renewable and non-renewable resources for food, fuel, and fiber production is necessary for commercial agricultural production. The challenge is to use those resources in ways that are sustainable. The alternative—unsustainable consumption—will eventually result in interruptions and diminished output of harvested products. Most prominent among contemporary threats to agricultural sustainability are:

- Available land area and soil productivity;
- Water quantity and quality; and
- Access to biological/genetic resources.

Loss of land area to agricultural production is seen as a major threat to sustained agricultural output; this condition is particularly significant in areas that are in close proximity to urban areas.[12] Increasing regulation and higher-value, alternative uses have greatly diminished the land area that is available for crop and livestock production. Vast areas of farmland have been converted to housing developments, industrial parks, highways, parking lots, and strip malls.

European countries have set agricultural land aside and will not allow it to be available for alternative uses; it must stay as agricultural land. Some of our states have enacted laws to preserve open spaces, but the results have been mixed. What is needed is a more comprehensive understanding of the cultural, economic, physical, and social factors that drive the United States to divert its agricultural land-base to other uses and to find scientifically sound and politically acceptable ways to preserve it.

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[12] American Farmland Trust (www.farmland.org) reports that 79 percent of our national fruit production, 69 percent of our vegetable production, and 52 percent of our dairy production are in counties at risk from urban expansion. "Our study really pointed out that it is the best farmland that we are losing." (Robyn Miller, AFT)

Due to the consequences of pollution (see below) and the extraction of soil nutrients, the health of the land that remains available for agricultural production is often threatened. Some farmers faced with economic stress sell their rights and allow biosolids to be spread on croplands, risking contamination from heavy metals and microbes. Others use land as a receptacle for the animal wastes and organic byproducts of farming and ranching. Agricultural producers need good alternatives, greater support, and increased understanding of the consequences of their choices. Accumulating mistake on top of mistake will further diminish the ability of our agricultural lands to provide safe, accessible, and affordable food supplies for the burgeoning population.

Fertilizer Management: Current estimates indicate that in some years, on some soils, as much as 50 percent of the nitrogen applied by farmers is not utilized by their crops. The balance remains unaccounted for—it has been diverted to someplace else in the environment. Another recent study concluded that if agricultural fertilizer continues at its present rate, the increased global demand for food over the next 50 years would be accompanied by a 2.4- to 2.7-fold increase in nitrogen- and phosphorus-driven water pollution of fresh water and marine ecosystems (Tillman et al., 2001). The movement of nitrogen from cropland to water supplies occurs as nitrates leach below a crop's root zone and/or when soil erodes from farmland. In addition, nitrous oxide—one of the major greenhouse gases attributable to agriculture—is released when soil fertilizers are not completely used by crops. This release has been reported to cancel-out the positive capture of another greenhouse gas—carbon dioxide—that results from implementing improved farmland management practices (Robertson et al., 2000).

Some warn that, given present trends, relying on the gains possible through conventional plant breeding, plow-based cropping systems, and methods for applying plant nutrients will exacerbate rather than improve the impact of agriculture (and especially agricultural chemicals) on the environment.

Better Environmental Pollution Prevention and Management Schemes: Agriculture is now seen as an enormous resource that could be used for remediation of environmental pollution. Opportunities do exist to genetically modify plants and microbes to remove pollutants from contaminated land. This is just one of many other examples of ways agriculture can contribute to environmental pollution management.

In addition to previously mentioned problems, agriculture also contributes to environmental pollution through misuse of pesticides, the erosion (both by wind and water) of cultivated land, and the generation of agricultural wastes (see below). New knowledge is needed to allow agricultural producers to contribute to environmental protection and remain financially viable. Ways must be found to mitigate, avoid, or manage agriculturally caused pollution that fits with the need to feed, clothe, and house our citizens and allows farmers to make a profit.

A Greater Dependence on Science-Based Environmental Regulations: Federal and state laws that assure air and water quality, regulate land uses, preserve wildlife habitat, assure the welfare of domestic animals, regulate working conditions of laborers, and guard against invasive species all impact agricultural efficiency and productivity, at least to some degree. New knowledge is needed to fully understand the trade-offs involved and to develop alternatives that give the necessary assurances and provide the necessary freedom to farm.

To date, the federal commitment to supporting regulatory decision-making that might affect agricultural producers has fallen to agencies outside the federal-state partnership. This process has had significant consequences for agriculture. A concerted effort is needed to support scientifically sound regulatory decision-making, through directed research. Land-Grant Universities should assume this expanded role.

Technology-based Waste Management Solutions: A report published in 1995 by the Council for Agricultural Science and Technology described the wastes[13] generated in the food production and processing industry in the United States.[14] The report emphasized the need for better management and utilization of such wastes to reduce the potential for environmental pollution and increased economic returns to farmers and processors.

It has been increasingly difficult for producers and processors to handle and dispose of such waste without creating significant environmental risks and other negative impacts. Although efforts have been made to recycle much of the waste (e.g., through land applications) a great deal remains either underutilized or is not being used at all. Large accumulations of agricultural waste pose potential health and environmental concerns in terms of air, soil, and water contamination.

The current procedures of handling food-processing wastes are increasingly expensive due to greater disposal costs and stricter environmental regulations. Animal wastes are of major concern because of their massive quantities as well as their potential for environmental pollution. The current trend of increased animal confinement has further aggravated the problem (See Challenge 2).

Crop residues represent a large amount of organic material that is available every year for producing products such as fuel, biogas, or animal feed. It also can be kept in the field as a source of soil organic matter. However, crop residues could be much more highly utilized.

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[13] Wastes identified in the report are from, but not limited to, animal (dairy and beef cattle, poultry, and swine), crop residues, food processing industry, and seafood industry.

[14] The food processing industry in the United States has been successful in reducing the amount of waste it produces through new processing technologies. It also has pushed to develop industrial-use products from wastes such as oils, feed, feed additives, bioplastics, solvents, and biochemicals. Similarly, the seafood processing industry is developing new ways to deal with wastes.

New Natural Resource Management Technologies that Provide Multiple Options for Farmers, Foresters, Fishers, and Ranchers: Invariably, the best solutions to complex ecological problems rest with offering multiple options that can be adopted in varying combinations. Single, "silver bullet" solutions to environmental problems rarely work. Providing a menu of options to farmers and ranchers requires significant investments in research and technology development, education and technology transfer, and implementation outcome monitoring to be sure that objectives are being met. Rarely have these types of investments been made for environmental protection programs in agriculture.

We see a worrisome trend toward regulating the farming and ranching practices that impact the environment without a thorough understanding of the commercial, economic, or biological consequences. We believe that public-sector science can help to fill these knowledge gaps and help to develop more scientifically sound practices. We also believe those new practices might most effectively be implemented by farmers and ranchers as voluntary choices.

CONSEQUENCES OF IGNORING THE NEEDS

The sheer volume of agricultural waste that is generated in this country every year dictates that research is needed in this area immediately. Agricultural waste, especially animal waste, has been implicated as a major source of both point and non-point source pollution to our surface and ground water. Ignoring this need for research could result in serious consequences in terms of public-health hazards and environmental pollution, or increased public opposition to modern food production and processing practices (see Challenge 2).

The need to find more environmentally friendly methods to assure the health of crops has long been recognized but has gone mostly unaddressed (Anne Simon Moffat, *Science* 292:2270-2273. June 22, 2001). The scientific possibilities have become more attainable with the advent of genetic engineering, but much research remains to be done. For example, very little DNA sequencing of either the major agricultural crops or their fungal or bacterial pathogens—with an eye toward the development or enhancement of pest resistance—has been conducted. Similarly, investments in food-animal DNA sequencing have been meager. Even less investment has been made in understanding the genetics of agricultural pathogens and pests. Without a fundamental understanding of the nature of pathogenesis and resistance mechanisms, we will be limited to conventional methods of maintaining crop and livestock health, many of which are considered incompatible with our national environmental goals.

SPECIFIC OBJECTIVES OF A NATIONAL RESEARCH PROGRAM

A national research program encouraging environmental stewardship should:

- Target improved nitrogen-use efficiency, with a goal of achieving a national standard (e.g., where at least 75 percent of the applied nitrogen is used by the harvested product and other crop biomass);
- Expand the nation's plant breeding efforts to include research on plant pests and pathogens that are not currently controlled by traditional plant breeding or require the use of pesticides deemed to be "high-risk";
- Intensify the use of computer applications that are integrated with basic pest and pathogen research to develop improved disease prediction models, decision support systems, and customized record keeping. This effort will need to produce more effective integrated and sustainable pest management strategies including an improved ability to delay, prevent, or otherwise manage new pest and pathogen species;
- Invest in genome sequencing of selected pathogens and pests;
- Create new research activities to address the issues of invasive species and bioterrorism;
- Develop and deploy new crop- and soil-specific "best management practices" to encourage effective nutrient recycling; and,
- Develop new technologies that limit and/or use agricultural wastes, especially animal waste, including:
  - "Precision farming" technologies to ameliorate agricultural wastes;
  - Improved practices for land application of animal wastes and biosolids to assure environmental harmony;
  - Alternative uses for agricultural wastes, including non-food uses for underutilized byproducts and residues from the food processing industry;
  - Better ways of processing agricultural wastes including bioconversion, pretreatment of waste, biosolid separation, and on-farm production of fuel and biogas;
  - Improved methodologies and research on economic incentives that encourage greater use of harvest and processing residues for soil improvement or as feedstock for industry; and,
  - New ways to harvest key nutrients from animal waste.

POTENTIAL IMPACTS OF THE RESEARCH

Achievement of these research objectives has the potential to:

- Further reduce the dependency of U.S. agriculture on pesticides, tillage, and open-field burning; and,
- Reduce the impact agriculture has on the environment (e.g., water pollution or greenhouse gas emissions).

Gains in efficiency by reducing pesticide use and fertilizer applications represent considerable potential cost-savings for individual producers (by reducing the need to purchase these chemicals). The deployment of more pest- and disease-resistant crop species and livestock breeds, combined with more judicious applications of pesticides and drugs, represents a major opportunity to assist U.S. agriculture economically as well as environmentally. This approach, combined with the development of new technologies for no-till farming, offer more sustainable agricultural production than is available currently. The goal would be to reduce the amount of pollutants, sediments and dust, water-mediated runoff, and wind erosion of soil from farms and to achieve a reduction in total use of pesticides and fertilizers. Agricultural land, if managed as an ecosystem, would meet more of the environmental standards currently found in natural ecosystems. Through the use of modern information and precision farming technologies, soil, nutrient, and pest management procedures could be customized for each field or area within a field, just as nutrition and medicine are customized for individual people.

The potential **outputs** from this research would be:

- New environmental management technologies; and,
- More options and alternative uses for the byproducts of agriculture.

The potential **outcomes** would be:

- Reduction in the quantity of agricultural wastes produced on- or off-farm;
- Better use of animal waste, crop residues, and food-processing industry waste;
- Increased production of fuel and feed from waste agricultural byproducts;
- More efficient use of commercial fertilizers and pesticides, and reductions in nutrient losses; and,
- Increased soil fertility.

The potential **impacts** of this research include:

- Less environmental damage from agricultural production practices including:
    - Cleaner air
    - Better water quality
    - More productive soils
    - Better economic returns for producers and processors

Additionally, this research will improve the public perceptions of agriculture and will help to develop a better image of the industry as a sustainable enterprise.

Efforts to decrease the impact of agriculture on the environment and people will depend on finding:

- Ways to significantly increase fertilizer-use efficiency, especially nitrogen and phosphorous;

- Methods to manage and even exploit the wastes generated by agricultural production activities; and,
- Ways to use genomics and genetics for the control of insects, insect-vectored viruses, plant parasites, and root diseases that are not currently controlled by conventional plant breeding.

Advances on these research topics must include the development of new crop varieties and livestock breeds, fertilizer management systems adapted to low-till and no-till farming systems, and reduced off-farm movement of sediments and dust. It also will require more intelligent use of production and processing wastes and crop and livestock residues, either as biomass or to improve soil quality. All of the tools of modern biotechnology, information technologies, and precision farming technologies must be available for use in these scientific and technical frontiers, which are vital to the sustainability of agriculture. These methods also must take into account the need to increase the profitability of farming.

Challenge 5

We can improve economic return to agricultural producers.

BACKGROUND AND RATIONALE

Currently, many segments of U.S. agriculture are just not profitable. This is illustrated by the huge government payments that have been made to agriculture in the past few years (greater than $70 billion). In fact, federal government payments accounted for about 50 percent of net farm income in 2000.

Fundamentally, there are two strategies being explored to address the difficult economic circumstances being faced by today's farm communities. The first is for producers to try to become increasingly efficient in their production techniques in order to compete in the global marketplace. The second strategy is to focus on local or regional markets where the local or regional producer may have a competitive advantage.

Farmers who produce for the global commodity market must be efficient, low-cost producers who can make a profit. These agricultural producers, however, face constant challenges from world commodity prices, U.S. exchange rates, commodity shortages or overproduction, international economic instability, and uncertainties in environmental and health regulations. In contrast, to compete in local and regional markets growers need to differentiate their products and develop market niches and specialty products that command higher prices in local and regional markets. This often involves the development of a unique product through some type of value-added process or production methods (e.g., organic farming) to add value to raw materials. Producers at all levels are affected by increasing transportation and energy costs, uncertain water supplies, changing consumer preferences, and environmental and labeling concerns. At all of these levels, U.S. agricultural producers need more information to help them take advantage of various marketing options and increase their profitability.

The term "conventional" represents the accumulated knowledge and wisdom about the most widely accepted procedures and techniques used to grow crops and raise livestock. Conventional agriculture has typically focused on commodities and is grounded in the premise that the primary objectives is to produce as much food and fiber as possible for the least cost. Conventional agriculture is driven by the twin goals of productivity and efficiency. More specifically, the organizational underpinnings of conventional agriculture rest within both experimental biology and neoclassical economics.

The logic of experimental biology presumes that increasing agricultural output is the primary goal of conventional agriculture. Neoclassical economics, on the other hand, posits that optimal efficiency and maximum profitability in production agriculture can be achieved by balancing the four factors of production: 1) land; 2) labor; 3) capital; and 4) management or entrepreneurship. These four factors form the basis of the production function.

The proponents of conventional agricultural production in the United States have been the Land-Grant Universities, the USDA, and, more recently, large agribusiness firms. The Land-Grant University system brought the methods of scientific research to agriculture. In the past, the emphasis in the classroom and research laboratory has been on the production of "commodities." As part of this process, the different agriculturally related disciplines that formed over the past 120 years (e.g., agronomy, plant pathology, animal sciences, nutritional sciences, plant breeding, agricultural economics, entomology, and so forth) broke apart "farming" bit-by-bit into disciplinary niches.

The goals were the same, however, across these disciplines. In the plant sciences, attention was directed at increasing yields by enhancing soil fertility, reducing pest and disease damage, and developing new varieties with higher yield potential. Animal scientists, on the other hand, focused on animal health, nutrition, and breeding as the means to increase efficiency. The scientific and technological advances wrought by Land-Grant University scientists were filtered through a farm management model that championed sets of "best management practices" as the blueprints for successful and presumably profitable operations, at least for the early adopters.

Industrialization is the primary force behind the conventional model of agricultural production. According to Welsh (1996), "Industrialization has traditionally referred to the process whereby agricultural production has become less of a subsistence activity and more of a commercial activity." While it is difficult to pinpoint an exact starting date for the industrialization process in the United States, it is safe to say that the mechanization of farming in the early part of the 20th century was a first giant step that led to increasing intensification, concentration, and specialization of commodity production.

The industrialization of agricultural production proceeded relatively unabated from the 1920's through today. During this era, farms became larger in size and fewer in number. Land was used more intensively, and yields per acre of farmland increased dramatically. As a result, the amount of farmland decreased while capital investments on the farm increased. Management skills became critical for economic survival. At the same time, farms were woven into ever-tighter marketing channels.

For farmers and rural communities in the United States, the globalization of the food system means that a much smaller number of producers will collaborate with a small number of processors in a highly integrated business alliance. Drabenstott (1999) estimates that "...40 or fewer chains will control nearly all U.S. pork production in a matter of a few years, and that these chains will engage a mere fraction of the 100,000 hog farms now scattered across the nation." Gary Hanman, chief executive officer of Dairy Farms of America (the largest U.S. dairy cooperative), noted recently, "We would need only 7,468 farms [out of over 100,000 today] with 1,000 cows if they produced 20,857 pounds of milk, which is the average for the top four milk-producing states" (*Northeast Dairy Business*, 1999:11). The consequences are clear: "...supply chains will locate in relatively few rural communities. And with fewer farmers and fewer suppliers where they do locate, the economic impact will be different from the commodity agriculture of the past" (Drabnestott, 1999).

Most small farms did not report adequate income to cover expenses in 1998. As a result, the USDA declared these small family farms, on average, to be less viable businesses than large farms. Households operating small farms relied on off-farm income to remain solvent. According to a recent USDA report, most farms are small family farms with sales of less than $250,000. These farms accounted for 68 percent of the land owned by farmers. Yet small farms accounted for less than one-third of the value of agricultural production. The emerging pattern has raised alarm in the political circles interested in preserving the American family farm.

These data suggest a need to redirect attention to the economic profitability of agricultural producers of varying types, especially those classified as small family farms, because these enterprises account for the vast majority of all U.S. farms. Innovative strategies based on new knowledge and technologies are desperately needed to enhance the competitiveness and viability of these farming operations.

Risk has been defined as "uncertainty that affects an individual's welfare" and is often associated with adversity and loss. Farming has always been a risky business, with many hazards ranging from uncertainty in price and yields to personal risks associated with injury and poor health. But changes in structure of U.S. agriculture and the global economy have presented farmers and ranchers with new risks.

The continuously changing political, economic, social, and environmental aspects of agriculture create increased complexity and new challenges for producers in managing their enterprises so that they are viable and profitable. For example, the advent of agricultural biotechnology holds the promise of reducing some risks in production but may produce costs for other specifically needed inputs. It also poses greater market uncertainty for the resulting products. Further, a shift toward less government intervention resulting from the 1996 Freedom to Farm Act requires producers to be very well informed and make better decisions in the use of risk management. Thus, decision-making for producers is now more complex, and the corresponding risks are greater than ever.

There are various ways of classifying the risks associated with agriculture. One classification distinguishes business risks from financial risks. Sources of business risks in farming include:

- Market- or price-risk fluctuations;
- Production risks associated with variability in weather, diseases, and pest infestations;
- Technological risks associated with technological changes;
- Legal and social risks, such as government programs, taxes, credit, trade, and environmental policies; and,
- Human sources of risks associated with labor and management, the health and well-being of key individuals on the farm, and changing objectives of individuals and farm family members.

Financial risks, on the other hand, are additional risks borne by farmers related to the equity they have in the farm operation, the availability of loans, and the costs of credit. In short, there are many risk factors that producers need to assess in their farming operations.

Without question, risk planning and careful management are essential to a successful farming operation. Risk planning requires a wide range of contemporary, valid, and accurate information. While there are many information resources available to producers, the sheer volume of information needed, and the need for that information to be up-to-date in a changing environment, results in an almost overwhelming situation for small enterprises. It is clear that for many small farm operations, the owner/operator needs reliable, improved decision-making support systems.

The values and goals of producers are additional considerations in the successful management of risks. For instance, some traditional values, such as individualism and independence, may need to be reconsidered when assessing alternative risk management strategies. Studies have shown that producers differ in both their assessments of risks and their ability to take risks. For example, a 1996 USDA survey found that producers are most concerned with changes in government laws and regulations, decreases in crop yields or livestock output, and uncertainties in crop prices. Producers of major field crops tend to be more concerned with price and yield risk, while livestock and specialty crop producers tend to be more concerned with changes in laws and regulations. Geographic differences in the assessments of risk factors also have been observed.

The Economic Research Service's (ERS) eight-fold typology of farms also calls attention to the variability of today's farms in structure, size, and other characteristics. Associated with these variations are presumably differing goals. For instance, the goals of different scale operators are very likely different. And the kinds of resources available to the different scale producers, and their ability or willingness to take risks, probably differ as well. The expectation is that no one prescription for risk management is likely to fit all farming situations.

Determining the long-range research agenda to address these needs will require input from both traditional and non-traditional stakeholders. Growers' input is needed, but the input of consumers and decision-makers in the marketing channels also is essential to identifying the full range of new marketing opportunities. Examples of the needed information include:

- Consumer surveys and focus groups to assess consumer preferences, both domestically and world-wide;
- Better understanding of the marketing channels that exist at the local, regional, national, and global levels as well as the entry points that offer access to farmers;
- Food-processing and nutrition studies to aid in the development of new products and processing methods that allow producers to access specialty markets; and,
- Ways to reduce production costs so growers can be competitive in global commodity markets.

Thus, while efficient production systems can improve the profitability of agriculture, agricultural producers also need a better understanding of food economies at all levels. The needs and preferences of consumers and retailers in these markets differ, as do the factors that affect commodity prices. Armed with good information about how these various markets work, U.S. agricultural producers can make better choices about which markets to produce for and how to best sell their products in those markets.

Focused research activity in the areas outlined above will help U.S. producers increase their net income and profitability. Most of the research that is needed to improve farm and ranch profitability is applied in nature, as the objective is primarily to improve and expand marketing opportunities for producers. These opportunities will vary geographically and temporally because markets are dynamic institutions that are constantly changing. Hence, an ongoing research effort in this area is needed.

Some of these research needs can be met in a relatively short time frame (consumer preferences, value-added projects, marketing strategies). Other research needs (effects of globalization, effects of environmental and economic uncertainties) will require longer-term initiatives. Since consumer preferences change over time, marketing strategies will need to be redesigned constantly, and new value-added products will need to be created on an ongoing basis. Thus, the research will need to be continuous.

CONSEQUENCES OF IGNORING THE NEEDS

The emphasis on commodity production by Land-Grant Universities, farmers, and large food corporations has resulted in a “cheap,” abundant, and relatively safe food supply. Unfortunately, it also has left many rural communities and regions in various stages of economic stagnation. Continuing down this path may exacerbate these social problems, likely on a global scale.

Failure to develop a better understanding of how local, regional, national, and global food economies affect the economic return to U.S. producers will result in the continued decline of agriculture in this county. In addition, ignoring the need for research on increased market globalization will disadvantage many large-scale U.S. producers, which will have ripple effects throughout the U.S. economy.

Failure to develop alternative marketing strategies and value-added products for small-scale producers will affect the viability of many rural communities. In many parts of the country, rural landscapes may give way to development pressure if agricultural producers cannot remain profitable.

Failure to design improved decision support systems for risk management in farming is likely to have the greatest immediate and negative impact on the five types of small family farms in the ERS study. This negative impact would be significant in that these farms comprise approximately 90 percent of U.S. farms. Without improved decision support systems, it is quite likely that many of these farms will cease to exist.[15] Larger family farms and non-family farms, on the other hand, are likely to become more diverse enterprises and to have more resources (including consulting resources), enabling them to better manage and overcome risks.

Significant economic and social impacts also would be experienced in rural communities.[16] Businesses and services, dependent in part at least on the surrounding family farm population, would be less viable. The remaining family farms would grow larger, but would not create sufficient clientele to maintain many businesses and services in the surrounding rural communities. These rural communities would in turn continue to lose population.

Agricultural concentration, with vertical integration, would be another likely consequence of not investing in this research arena. This would have an impact on both producers and consumers.

SPECIFIC OBJECTIVES OF A NATIONAL RESEARCH PROGRAM

Farmers need to be empowered to identify and analyze their risk management needs as well as to design alternative models best suited to their own situations. Universities and agribusiness have technical expertise to contribute to the accomplishment of these objectives. Government has a role in making user-friendly support systems available. For example, in South Dakota, the state government has taken the initiative to provide all schools in the state with Internet access. Farmers who do not have such access on their property can gain access through schools or other government-supported facilities in the

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[15] The consequences of ignoring the need for improved decision support systems for risk-based management in farming and ranching can be summed up in the following publications: "Are there family farms in our future?" (Purdue University, Cooperative Extension Service); and "Most small-farm typology groups did not report adequate income to cover expenses in 1998. Households operating these farms relied on off-farm incomes." (ERS Ag Information Bulletin No. 769)

[16] It has become apparent that a more community-focused agriculture is emerging in regions that have been hit hard by global competition. Massachusetts, New York, and other states in the Northeast, for example, are in the vanguard of relocalizing their food and agricultural systems. Large-scale, industrial farming has largely bypassed this region and consumers must rely on food produced elsewhere.

communities (such as extension offices, libraries, or senior centers). Schools and the Cooperative Extension Service could take the lead in helping farmers learn how to use new communication technologies. Further, government may have a role in developing policies to enable some strategies for risk management that could not be implemented under current policies. For example, some strategies to reduce risk through horizontal linkages among farmers and even across geographic regions (Saxowsky and Saxowsky, 1999) may require legislative changes.

Based upon the above objectives, a national research strategy should:

- Develop alternative, innovative models for risk-based management strategies that correspond to the varying needs of different types of producers;
- Design "user-friendly" support systems to make use of current communication technologies;
- Develop a better understanding of:
    - The effects of market globalization, environmental impacts, and economic uncertainties on U.S. agriculture;
    - Marketing strategies that enable U.S. producers to compete in local, regional, national, and global markets; and,
    - Consumer preferences for produce and food products.
- Develop value-added products and niche markets for small-scale producers;
- Develop improved strategies for community-supported food production systems; and,
- Develop strategies that orient agricultural production toward local and regional markets and meet the needs of local consumers rather than national or global mass markets.

This will entail changes in the way we:

- View agriculture as an integral part of rural communities, not merely as the "production of commodities";
- Meet producer and consumer concerns for more high-quality and value-added products;
- Substitute, at the farm level, more labor-intensive and land-intensive practices, and focus less on capital intensiveness and land extensiveness research;
- Encourage producers to rely more often on indigenous, site-specific knowledge and less on a uniform set of "best management practices"; and,
- Support producers in forging direct market links to consumers rather than indirect links through middlemen (wholesalers, brokers, processors, etc.).

POTENTIAL IMPACTS OF THE RESEARCH

As a result of this research, agricultural producers will have better access to niche marketing and new value-added products to offer consumers. Small-scale producers would have a larger share of the local and regional food dollar, and large-scale producers will be more competitive at the national and global levels.

Communities that nurture local systems of agricultural production and food marketing, as one part of a broader plan of diversified economic development, can gain greater control over their economic destinies. A community-supported food system creates new opportunities for farmers and preserves farmland. Local food systems keep food dollars circulating in the community and have important multiplier effects. Community-based food production systems also can enhance the level of social capital among their residents, contribute to rising levels of civic welfare and socioeconomic well-being, revitalize rural landscapes, improve environmental quality, and ultimately, promote long-term sustainability.

Investments in this area of research could, in turn, be expected to have the following **outputs**:

- Farmers with varying types of operations would have more applicable risk management tools, business and management options, and strategies available to them; and,
- Farmers would have easier and more user-friendly access to up-to-date information on risk management.

Research **outcomes** would be:

- Small family farms would be more successful in risk management;
- Variety in the types of farms would be maintained;
- Small family-farm businesses (the vast majority of farms) would be more viable; and,
- Trends toward food-production concentration would not continue.

The anticipated **impacts** would be:

- Profitable farms and related agricultural enterprises providing increased employment opportunities for rural residents;
- More economically-viable and vibrant rural communities; and,
- Greater assurance of national food and fiber security.

Challenge 6

We can strengthen our communities and families.

BACKGROUND AND RATIONALE

Rural areas in the United States are affected by intense national and international economic competition, increased responsibilities from the federal government to finance and provide public goods and services, changing demographics,[17] strict environmental regulations, changes in the structure of agriculture, and rapid advances in information technologies that seem to be bypassing rural communities. These forces bring a wide variety of economic, social, and environmental issues (e.g., conflict between agricultural and environmental interests, land use and property rights disputes, invasion of the large "big-box" retail stores) to the attention of policymakers, local citizens, and various stakeholder groups from inside and outside of the community. Since the actions that communities take to confront and resolve these issues generally create winners and losers, stakeholder groups and local citizens need access to knowledge that will ensure their conflicts are resolved and their voices are heard.

Scholars that study families and communities see the drivers of changes as:

- Shifting population;
- Inadequate community structures; and,
- Inadequate workforce competencies.

Shifting Populations: A rural community's success at developing an agenda for social and economic development is largely determined by the extent to which local residents and interest groups can agree upon and promote common values and share opinions.

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[17] According to a recent U.S. Census release (Perry and Mackun, April 2001), the U.S. population increased to 281.4 million in 2000, an increase of 13.2 percent from the 1990 Census. Population growth varied geographically, with large population increases in some areas, and little growth or decline in others. Every state grew in population between 1990 and 2000. Growth rates varied from a high of 66 percent in Nevada to a low of 0.5 percent in North Dakota. While all states showed population growth, and most counties also grew, some counties lost population. Counties losing population were most often located in agricultural areas. One band of counties that lost population (in some cases declining more than 10 percent) stretched across the Great Plains from the Mexican border to the Canadian border. A second band of slow growth counties was observed in much of the interior of the Northeast and Appalachia, from Maine through western Pennsylvania and West Virginia to eastern Kentucky. On the other hand, rapid population growth occurred in counties in the interior West and much of the South. Growth of population concentration continued both within and adjacent to metropolitan areas.

The increased mobility and diversity of the U.S. population contributes to a constant influx of new and divergent values into a community. Furthermore, the decrease in day-to-day interaction among community residents makes it more difficult to identify a set of shared values within a community.

Varying population growth rates, together with the increasing diversity and general aging of the population, are significant when considering strengthening communities and families, as well as for developing an understanding of the social dynamics and decision-making processes. Urban areas with significant population growth have gained in human resources for economic development, including labor pools. At the same time, they often encounter new challenges in terms of social dynamics and interpersonal interactions related to the increased diversity of their populations. Rural areas, on the other hand, continue to face challenges in sustaining their communities as their population base continues to shrink and grow older.

Another consequence of the varying migration rates is that areas losing population or showing low rates of growth have experienced difficulties in securing adequate labor to meet the needs of existing employers as well as an inability to attract new employers. In some cases, it has been necessary to recruit temporary labor from outside of the region. While meeting a labor need, some strategies have often been accompanied by problems in securing adequate housing for temporary laborers and in the social dynamics of the community, especially when the temporary laborers were racially or ethnically different from the dominant community population.

Community vitality: In terms of community vitality, it must be emphasized that globalization and technological change are major factors influencing communities. Many of these communities lack the trained public-sector staff to deal with the increasingly complex forces that affect them. Particularly in rural areas, it is not enough to supply Internet access. Training programs are needed to allow local governments, schools, small businesses, private citizens, and non-profit organizations to effectively use this new technology. Congress appears to be moving to electronic exchange of all of its inter-governmental communications and documents, etc., but no one is assuring that rural areas will be able to participate in this process.

Entrepreneurship: Another potentially important avenue for ensuring community vitality is through support of the self-employed, including community-based entrepreneurship.

Urban residents have an interest in the preservation of rural communities. In particular, cities are becoming more congested, and the health-related and economic costs of living in them are rising. Thus urban residents have a vested interest in assuring that rural residents have opportunities to remain in rural communities (e.g., through community vitality initiatives). Many urban residents also value the option of being able to return to their rural roots upon reaching retirement.

Unintended Consequences of Federal Policies: More research also is needed to understand how federal policies are affecting the vitality of rural areas. For example, researchers are finding in the Northeast region that the impact of the North American Free Trade Agreement (NAFTA) has had a negative affect on employment. Job losses and reduced hours or wages in rural areas are twice that of urban areas. A few years ago, a research study showed that federal spending in urban areas was allocated more to investment-type activities (which generated further economic growth), while federal spending in rural areas was allocated more to consumption-type activities (e.g., welfare, food stamps, etc.). Rural areas, and poverty-stricken areas in particular, tend to lack individuals who have the skills that would allow them to participate effectively in the grant-seeking process that could generate additional resources to enhance the economies of these communities.

Inadequate Community Structures: The viability of locally based economic systems is directly tied to the collective efforts of the communities to which they belong. Goldschmidt (1978) has illustrated the benefits of small-scale, locally oriented enterprises. He found that communities in the Central Valley of California that had an economic base made up of many small, locally owned firms had higher levels of well-being than communities where the economic base was dominated by a few, large absentee-owned firms. More recent research has reaffirmed that communities reap many positive benefits by embracing a *community capitalism* model of economic development (Tolbert et al., 1998).

Communities that nurture local systems of agricultural production and food marketing as one part of a diversified economic development plan can gain greater control over their economic destinies. Enhancing the level of interaction among community residents is an effective tool in raising the level of civic welfare, revitalizing rural landscapes, improving environmental quality, and ultimately promoting long-term sustainability.

Communities can buffer and shelter themselves from the negative effects of globalization only if they develop a supportive infrastructure, maintain a farmland base, and provide the technical expertise so that farmers and processors can successfully compete in the local marketplace against the highly industrialized, internationally organized, corporate food system. Communities, organizations, individuals, and local governments have many tools that can be used to effect change and move toward a more "civic agriculture" (Lyson, 2000). Some of these tools are:

- Food policy councils that put agriculture and food issues on the political agendas of local communities;
- Local economic development efforts to support community-based food processing activities;
- Zoning codes that allocate land for non-farm development, natural preservation, and agricultural production;
- Institutional food acquisition practices that integrate local food production directly with community needs; and,

- Educational programs to increase agricultural literacy among both children and adults, including school and community gardens, summer internship programs, and community-farm days.

Community-based coalitions can help communities overcome the obstacles to economic development by providing a formal structure to convey and coordinate the activities of a wide variety of groups and individuals. Coalitions can provide additional benefits to society. They can be used to spread the high administrative and legal costs of promoting social change over a large number of groups and individuals who share a common objective. Coalitions also may provide leverage against large, external entities that attempt to exert their power and political will on communities. Finally, coalitions, as an integral part of a group learning process, can help individuals and groups develop clear and consistent long-term strategies.

In the future, environmental, labor, and community-based coalitions will be increasingly important in rural areas as a forum for sharing information and resolving conflicts. Ultimately, this may enable diverse groups in a community to reach a consensus and to speak with a unified voice on issues of common concern. New models for successful coalitions will provide improved means for promoting democratic change.

Workforce Competencies: On an annual basis in this country, millions of people enter the job market for the first time. Millions of others move in and out of the job market and up and down the career ladder in their workplace. Workforce preparation is required for this to happen efficiently and effectively; several models have been suggested and/or are operational.

CSREES/USDA, in a working document titled "Workforce Preparation: Preparing Citizens for Job Flexibility and Effectiveness" stated the following under the section labeled "Need for Workforce Preparation":

> "Trends sweeping the United States and the world at the end of the 20th century and continuing into the 21st century are dramatically changing the way we work. These changes are impacting the economic security and stability of individuals, families, and communities. Young people matriculating in schools will require career skills in addition to formal education…. Special collaborations are required to reach youth who are no longer in formal education programs…. We can no longer expect to have one job, work for a single employer, or use the same skills or knowledge throughout one's lifetime…. Adults require updated skills, new career tools, and a greater involvement with technology to transition into new careers. The new work environment requires continuous training and lifelong learning skills to survive."

What then are the needs for workforce preparation, and what is the 'bottom line' in terms of models of workforce preparation? There is no "ironclad" answer to this question. However, it appears that any model for workforce preparation should:

- Be focused on providing economic security and stability for the workforce;
- Take into account that the vast majority of new U.S. workforce entrants over the next 10 years will be women and minorities, bringing with them various needs;

- Provide opportunity for continuous training and education (formal as well as non-formal); and,
- Provide opportunity for career advancement including transitioning into new and more challenging careers.

CONSEQUENCES OF IGNORING THE NEEDS

Wherever the production model of agricultural development takes hold, the commodities upon which the food system are built become "cheap." Simply stated, the U.S. emphasis on production efficiency has resulted in an abundant supply of a relatively narrow set of commodities (i.e., those that are easy to produce and process). However, as noted by one authority, ". . .there is little need for more food output from American agriculture" (Strange, 1988). Continuing down a path of ever-increasing production efficiency will lead to a greater concentration of agricultural production in fewer hands, erosion of rural communities and their cultures, depletion of resources, and degradation of the environment.

There is very little profit for farmers who produce the most basic commodities—corn, soybeans, wheat, and rice—for the global marketplace.[18] A turn away from a research focus on *production* and toward a focus on *development* requires investigation on how to reintegrate agriculture and food into local communities. The *development* model extracts value out of the commodity at the community level, before it moves the value-added products to the market place.

If the needs of our changing communities and families are not addressed, the quality of life will deteriorate, people's sense of satisfaction with life in their communities will decline, and families will experience increasing levels of stress. In urban areas, conflicts have been observed when residents are not prepared to deal with growth. Rural communities, on the other hand, experience a loss of services and community anchors such as churches, schools, and hospitals. Some fail due to dwindling population. Opportunities are lost if we fail to recognize the potential for new markets within our own changing populations and communities.

If the workforce preparation needs of this country are ignored, there could be any number of negative consequences. Paramount among them is the concern that the United States could lose its powerful economic position in the world. Just letting workforce preparation *occur* is not a practical option. Appropriate workforce preparation efforts must become a national priority.

Points to consider and processes known to be important to valid rural development research activities include the need to:

- Have community members involved in defining their needs, their values, and their future goals;

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[18] Consider that a box of Wheaties that sells for $3.00 in the United States represents only three cents to the wheat farmer.

- Develop new concepts for meeting a community's needs collaboratively among community members;
- In communities experiencing great change, refine conflict management techniques, especially when the change is in the population makeup of those communities;
- Pay close attention to families that are at different points in their life cycle (e.g., families with young children, families with school-age children, "empty nest" families, families with no children, and families of older persons); and,
- Take into account the changing needs, values, and goals of families with regard to health care, economic well-being, social relations, and the generational transfer of resources in farming families.

SPECIFIC OBJECTIVES OF A NATIONAL RESEARCH PROGRAM

Based on the above needs, the following specific research objectives should receive priority attention:

- Document, analyze, and relate to targeted objectives the variations that occur in communities in terms of age, race, ethnicity, income, and other social characteristics to find patterns of opportunity to build on community strengths;
- In communities of diverse populations, identify through survey methodologies patterns of common or shared goals;
- Understand the decision-making strategies used by families of varying structures;[19]
- Test the feasibility of developing new markets for specialty products grown in peri-urban areas (e.g., meeting the food preferences of new ethnic populations in urban areas);
- Determine the workforce needs of various sectors of the U.S. economy, as well as global economies.
- Define the most efficient and effective ways and means to achieve workforce preparation;
- Develop and evaluate new approaches to community strategic visioning, participatory decision-making, leadership development, and entrepreneurial economic development;
- Conduct an inventory and typology of coalitions that are active in rural communities; and,
- Identify and analyze the factors that lead to the formation and success of coalitions.

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[19] To include traditional nuclear families, including those of differing cultural/ethnic backgrounds, single-parent families, families headed by a grandparent, and families including a grandparent.

POTENTIAL IMPACTS OF THE RESEARCH

The research proposed here could be expected to have the following **outputs**:

- A better, more complete understanding of the changing make-up, needs, and social dynamics of the rural, peri-urban, and urban communities of our society; and,
- A better, more complete understanding of families of various kinds (composition, stage in the life cycle, culture, and location).

The research proposed here could be expected to have the following **outcomes**:

- Community members will develop a commitment to working together to realize shared goals;
- The limitations imposed by dwindling populations in rural communities will be overcome by embracing new models of community;
- Better designed and more appropriate policies and supportive services will be provided to families and communities;
- Farming and ranching enterprises will have increased opportunity to become oriented toward local market outlets that serve local consumers rather than national or international mass markets;
- Producers will profit from forging direct market links to consumers (rather than the indirect links provided by wholesalers, brokers, and processors);
- Farmers will be concerned more with high-quality and value-added products than with yield and least cost production practices;
- New economic opportunities will be created for farmers in peri-urban areas to develop specialty products; and,
- The food preferences of families in urban areas will be better met.

The research proposed here could be expected to have the following **impacts**:

- Communities undergoing great change, especially in terms of population diversity, will realize an improvement in the quality of life for all members, and they will experience minimal disruption from changing circumstances; and,
- Agriculture will be seen as an integral part of rural communities rather than merely as a means for the production of commodities.

This research will assist community groups by helping them to build more successful coalitions. Improved knowledge of coalitions will lower the transactions costs associated with setting up and maintaining successful coalitions. Better-organized and functioning coalitions are likely to lead to socially responsible, efficient, and equitable development and more livable rural communities.

Having a well-prepared and adequate work force will undoubtedly reap enormous benefits for this country and the world. Specifically, a well-prepared and adequate work force will help this country to maintain its powerful position in the global economy. Research is a key driving force to assure that this happens. It may be the most important impact that this research will provide.

Challenge 7

We can ensure improved food safety and health through agricultural and food systems.

BACKGROUND AND RATIONALE

Healthy People 2010[20] outlines 28 focus areas for improving the health of the nation's citizens. The goals of the focus areas are to: 1) increase the quality and years of healthy life, and 2) eliminate health disparities, such as cardiovascular disease, obesity, diabetes, maternal and child health problems, poor nutrition, lack of physical activity, and so forth. Cardiovascular disease remains this nation's number one cause for morbidity and mortality, while obesity has been characterized as having reached "epidemic" limits. At the same time, while we enjoy the safest food supply in the world, we are faced on a regular basis with incidents of food-borne illnesses for which our frailest (e.g., infants, elders) are particularly susceptible. For these populations, food safety often becomes a life-or-death situation.

In June 2001, incoming Senate Agriculture Committee Chairman Tom Harkin outlined his priorities for the next Farm Bill, which included strengthening food safety efforts and fighting hunger. Clearly, the Land-Grant University system and our agricultural production system are well positioned to address the food and health needs of this country. The Land-Grant Universities have a long history and tradition of focusing on food and health. *Healthy People 2010* sets before us an arduous task, but the scientists of the agricultural community (basic, applied, and social) are up to the task of meeting those goals, in concert with the other organizations.

People have known for thousands of years that specific foods improve certain health conditions, but only quite recently has science begun to explain why these foods are effective. Around the 4th century B.C., Hippocrates advocated eating liver as a remedy for night blindness. The active component, vitamin A, was not chemically defined as the effective agent until 1913. Now that science has developed the molecular tools for experimental discovery, researchers can determine the mechanism for a nutrient's actions at the cellular level.

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[20] "Tracking Healthy People 2010." U.S. Department of Health and Human Services. U.S. Government Printing Office. (November 2000.)

Scientific advances already have transformed our understanding of nutrition and the role of food in health. At the start of the 20th century, recurring nutritional deficiency diseases such as rickets, scurvy, beri-beri, and pellagra were thought to be infectious diseases. In the early 1900s, scientists discovered that food contained essential vitamins and minerals, and that a lack of certain necessary substances (i.e., nutrients) caused these specific diseases.

Actions taken based on this knowledge have saved hundreds of thousands of lives, if not more. In the United States during 1906–1940, approximately 3 million cases and 100,000 deaths were attributed to pellagra. By the end of the 1940s, pellagra had been nearly eliminated by the enrichment of flour with niacin, and the improved diet and health brought economic recovery to the country.

Although treating nutritional deficiencies was a major public health achievement, scientific research quickly identified a new challenge: chronic disease associated with diet. Scientists are rapidly discovering the important role diet plays in prevention and management of chronic diseases such as cancer, heart disease, obesity, and diabetes. We are just beginning to understand this role.

Epidemiological data provide evidence that relationships exist between certain foods and decreased risk for some diseases. However, we are far from being able to recommend specific nutrients to prevent or treat diseases. Having identified essential nutrients, we are still working to determine the amounts required for healthy individuals. Furthermore, the scientific consensus has returned to a more holistic view of the health properties of foods versus specific nutrients. For instance, the anti-carcinogenic property of some vegetables is most likely attributable to a host of phytochemicals, and not to any one single substance.

Ironically, the public has enthusiastically embraced some health claims that science has yet to prove, while neglecting others that have been proven for years. This pattern speaks to the need for behavioral science research to understand the acceptance or rejection of diet and health information by individuals. There is the need to ensure that we can interpret transitions from molecular events to whole-body metabolism events and integrate individual behaviors.

Safer and healthier foods are among the 10 great public health achievements of the 20th century, according to the U.S. Centers for Disease Control and Prevention (CDC). Yet despite tremendous improvements in food safety, the CDC estimates that food-borne diseases cause approximately 76 million illnesses, 325,000 hospitalizations, and 5,000 deaths in the United States annually. Clearly, additional research and intervention that enhances the safety of the U.S. food supply must be a high national priority.

More than 200 known pathogens are transmitted via food. The causes of food-borne illness include viruses, bacteria, parasites, prions, toxins, and heavy metals. However, focusing on known causes addresses only a small portion of the problem. Of the 76 million recorded cases of food-borne illness each year, the cause is definitively identified in only 14 million cases. Many of the pathogens of greatest concern today (e.g., *Campylobacter jejuni*, *Escherichia coli* O157:H7, *Listeria monocytogenes*, *Cyclospora cayetanensis*) were not recognized as the causes of food-borne illness just 20 years ago. Identifying the causes and mechanisms of food-borne illness is essential to their prevention and treatment.

Despite all that is known about food-borne pathogens, more information about their growth and survival is needed. The ongoing discovery of new pathogens continues to challenge scientific resources. Cost-effective control of pathogens through methods such as the hazard analysis critical control point (HACCP) system requires a thorough knowledge of the interrelationships between pathogens, foods, and the environment.

Scientists do not fully understand why and how certain pathogens cause illness. Why do some species cause illness while other related species do not? When the pathogen is ingested, how does it evade the body's defenses and cause the illness? How much of the pathogen must be present to cause the illness? Understanding the virulence factor(s), pathogenic mechanism(s), dose responses, and minimum infective dose of each pathogen are critical steps toward developing treatments or vaccines to control it.

New technology applied in food production can change food safety risks, in part by providing different opportunities for pathogens to enter the food system. Pathogens are especially difficult to control because they continually adapt to their surroundings and acquire new characteristics. For example, researchers are currently studying the impact of the use of antibiotics in food-producing animals on the development of antibiotic resistance among bacteria.

Changes in eating habits affect food safety risks as well as nutrition. The emphasis on attributes such as freshness (more minimally processed foods) and convenience (more ready-to-eat foods) has created safety concerns about acceptable storage and shelf life for products that will be eaten without reheating.

Food-borne illness risks extend all the way to consumption and storage of leftovers. Although reducing the pathogens in foods before they reach consumers will significantly reduce risk, proper food preparation, cooking, and storage remain essential. Researchers and educators need to find ways to effectively communicate food safety risk and modify risk behaviors. Creative and innovative approaches are needed.

Certain members of the population are especially sensitive to pathogens. For example, pregnant women, infants and young children, the elderly, cancer patients undergoing chemotherapy, organ-transplant patients, and AIDS patients all have compromised or altered immunity. The growth of these high-risk populations will affect the prevalence of food-borne illness. Efforts should target research for these populations.

Both diagnostic and the epidemiological investigation require detection of the illness-causing agent, creating a considerable need for faster, more sensitive tests for an increasing number of pathogens and contaminants. Molecular "fingerprinting" methods need to be improved and validated for tracking the sources of microbial contamination and investigating food-borne illness outbreaks.

Research funding is needed to develop a database with detailed information about the levels of specific pathogens in a variety of foods. Better cataloging methods will improve estimates of pathogen numbers on a food as it moves through the system. For example, preliminary results from federal testing for *E. coli* O157:H7 with new, more sensitive methods revealed that the pathogen is far more widespread than previously thought. Without accurate data, it is difficult to correctly identify high-risk activities and operations. Thus, the response to many food safety threats—by industry and regulators alike—has been primarily reactive.

Microbiological risk assessment is complex, in part because pathogens can multiply and adapt to their surroundings. These pathogens may enter the food supply at many points and from a variety of sources. Therefore, the capacity of each pathogen to reproduce at different points in the food system must be considered. Changes in food formulations and processing technologies continually provide new niches for contaminants to exploit, and for us to defend against. Adopting a proactive research approach will require increased focus on prevention and control. We need to better understand the microbial ecology of food-borne pathogens and the introduction of toxins. And we will need to learn more about risk factors along the food production-to-consumption continuum.

Although food-borne illness is usually considered minor and short-lived, some experts estimate that as many as 3 percent of all people suffering from acute food-borne illness develop serious consequences. For example, recent research indicates that *Campylobacter* infections may be the most common precipitating factor for Guillain-Barré syndrome, one of the leading causes of disease-related paralysis in the United States. Other examples include *E. coli* O157:H7, known to cause kidney failure in infants and young children; *L. monocytogenes*, known to cause miscarriages and stillbirths in pregnant women; and *Salmonella* infections, shown to lead to reactive arthritis. Further research is necessary to better understand the relationship between episodes of acute food-borne illness and chronic disease.

Control methods are only one part of the solution. Because they affect specific pathogens and toxins differently, no single control method will eliminate all pathogens and toxins from the food chain. The goal of comprehensive food safety research must be to prevent the entry of pathogens and toxins into food and drinking water, to prevent their spread and growth, and to inactivate or remove them as necessary.

Prevention and treatment of chronic disease will draw heavily on genomic research (i.e., the study of all the genes of an organism). Genomics help us understand why disease happens in one person but not another. Coupled with detailed knowledge of the healthful compounds in foods, genomic research opens the door to diets tailored for maximum individual health.

To assure a safe and secure food supply, we need several important factors to come together. We need:

- A broader understanding of the components of human health;
- An understanding of how nutrition and nutrients relate to physiological function;
- Increased emphasis on the components of wellness, rather than emphasis solely on disease;[21]
- A much more complete understanding of how foods and their components contribute to both positive and negative health impacts;
- More information about interactions, especially concerning how components activate or effect other components;
- A much more holistic approach to evaluate the role general and specific foods has in health;
- Coordination of "food" use/consumption with the medical profession's interventions (e.g., drugs) so that the two lines of research work together to provide better human health;
- Development of products that deliver the best that food has to offer in ways that still permit people to fully enjoy eating and living;
- New methods of delivering foods to people so that the individual needs (i.e., cultural, medical, etc.) of each consumer can be met economically and efficiently while people are at home or traveling; and,
- New ways to help people continue to enjoy eating and assist them throughout life in maximizing the benefit of eating.[22]

Although the choice of food is voluntary, the need to eat is not. Because most people are far removed from the production of food, and very few people can assimilate all of the information available about food, we are constantly questioning the foods we eat and their contributions to our own well-being. Clearly, as the information explosion continues, we will want new ways to deal with the need to use food as a part of our total health picture, while maintaining the pleasurable aspects of eating. The challenge will be to create a food system that supports health and well-being and still permits people the freedom to choose foods that meet their dietary preferences, whether those be personal, based on a faith/philosophical system, or derived from one's ethnic/cultural/historical background.

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[21] This is one of the ongoing goals of health research but is often slighted for supporting the quest to solve certain critical diseases.

[22] One extreme scenario might envision a device implanted in humans that quantitatively measures all food intake (actual quantity and a reasonable analysis/identification of the actual product consumed). A related computer system would then provide suggestions on appropriate foods, including suggested amounts, to maximize health benefits, taking into account a full personal medical record, food preferences, dietary patterns over time, and a real time evaluation of current status.

CONSEQUENCES OF IGNORING THE NEEDS

Consumer understanding of nutrition and health is improving, but corresponding changes in diet have been slow to follow. For example, data from USDA's *Continuing Survey of Food Intakes by Individuals* reports that, over a specific period of time, the awareness of the relationship between calcium and health increased, but the calcium intake by women age 20 and over did not change, continuing to average only 75 percent of the recommended daily allowance. Before we can capitalize on future scientific advances, we need to find better ways to produce diet modification.

Despite the increased number of "light" or "diet" foods in the marketplace, more Americans are overweight today than ever before. In addition, despite medical interventions, the incidence of obesity-related diseases has not declined significantly. Americans are gradually becoming more health-conscious—the share of calories from fat is declining and consumption of fruit is increasing in our diets. Still, most Americans are not consuming the recommended number of servings for fruits, vegetables, and whole grains—the base of the food pyramid.

Awareness of diet-disease relationships is only one of many factors in dietary behavior. We must learn why people do not adopt healthy eating habits or use dietary knowledge to develop successful intervention and education strategies. Particular emphasis should be placed on programs for children and adolescents to maximize long-term improvement in the health of Americans. Obstacles to healthy eating habits in elderly and within certain ethnic groups, especially recent immigrant groups, deserve special study because these groups will have increasing representations in national demographic patterns. They also seem to be most at risk.

If we are to maintain a safe, healthy, tasty, abundant, secure, and affordable food supply and preserve the freedom to eat the foods of our choice, then we need to develop new systems that can address the challenges we face.

SPECIFIC OBJECTIVES OF A NATIONAL RESEARCH PROGRAM

To provide a healthful food system of the future, research about how to maintain and improve human health, about food and food components, and the interactions between the two is needed. In turn, we will need to set systems into place that will integrate that knowledge, first technically, then in a way that is consumer-useful.

Part of the challenge will be to improve our knowledge of the constituents of the food supply. A key component of that work will be the need to accurately measure the components in a way that is relevant to medical and health. For example, the current concept of food composition needs to be much more refined. We need to quickly and easily determine the specific fatty acids in lipids, the actual amino acids in proteins, and the classes of carbohydrates that directly affect human metabolism. The amount and the function of a full complement of minor ingredients also need to be known. All of this information needs to be accurately conveyed to consumers in a "user-friendly" way.

Clearly, this is not the case with our current nutritional labeling information on food packaging (which, among its other faults, is one-sided with a high margin of error on the "desirable" side). Using a bar-coding system that can hold lots of information in small spaces, and rapid detection techniques that work in real time are some of the technical options. Both of these technologies could be combined with rapid printing to permit labels to be updated on an hourly (or even minute-to-minute) basis at the time of production. This process would more accurately reflect the detailed composition of the product at hand. The health-relevant composition of fresh products should be measurable at the time and place of purchase. As the weight/price label is printed, the nutritional/health information also would be encoded. And consumers would, of course, need a reader, which could be part of everyone's home computer system.

Restaurant meals, as actually served, should contain the same full spectrum of required information. All of this information, no matter where the eating occasion takes place, then needs to be transferred to the individual's computer data system, possibly via some personal digital assistants (PDAs). Thus, many new segments of an integrated food-industry information system will have an opportunity to contribute to assurances of food safety and health (and also to traditional food and medical interventions) in the food-delivery systems of the future.

To achieve these outcomes we will need to:

- Identify why some people adopt healthy eating habits while others do not;
- Develop biomarkers for nutrients and phytochemicals;
- Quantify the intake, absorption, and effect of these substances, and catalog the presence and activity of specific genes;
- Investigate the positive and negative biological effects on the entire human body of the various active components in foods;
- Investigate the health effects of probiotics and other non-digestible substances;
- Find the intake levels at which compounds create new risk;
- Consider the toxicity of other compounds in foods, and establish safe upper-limits for consumption;
- Find food substances that regulate the production levels of genes that affect overall health status or cause chronic disease, and design delivery systems to get the substance(s) to the right location;
- Create healthier food by using conventional and molecular methods to modify food components;
- Determine the feasibility of research approaches that can decrease food-borne illnesses, especially in populations at greatest risk, e.g., elderly, minorities;
- Describe the synergistic effects of "generally regarded as safe" (GRAS)[23] compounds for a better understanding of food safety issues;

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[23] Compound guidelines established by the U.S. Food and Drug Administration.

- Identify and fully characterize known and as-yet-unknown food-borne pathogens;
- Develop superior methods to detect and prevent the occurrence of pathogens and toxins in foods;
- Develop a database with detailed information about the pathogen and toxin levels in a variety of foods at each step of the food production, processing, and distribution system;
- Gather food-borne illness data through improved epidemiological surveillance;
- Foster more sophisticated, comprehensive pathogen risk-assessment models;
- Estimate the extent to which conditions will vary in different food production processes, and integrate probability models with dynamic models;
- Further evaluate existing food production practices for high-risk activities and the effectiveness of controls;
- Develop new control technologies and strategies, including lethal processes to kill pathogens on or in foods that are not suitable for heat treatment; and,
- Find ways to effectively communicate food-safety risks and modify behavior in food handlers, preparers, and consumers.

This research agenda will in turn require:

- Integration of research efforts among researchers and research and regulatory agencies;
- Sufficient funding to implement applied designs to test research hypotheses for which there are sufficient data to move ahead to the applied/intervention studies;
- Funding for novel and creative approaches to food safety and nutrition; and,
- Support for:
  - Research-based nutrition and food safety education and outreach efforts using applied approaches;
  - Nutrition and food safety interventions that are specific for each condition (e.g., the compound DHA for heart health or dementia/memory in the elderly; the compound CLA for diabetes);
  - Incentives for industry to partner with academicians in food safety and nutrition research efforts.

POTENTIAL IMPACTS OF THE RESEARCH

Among other positive aspects, the anticipated impacts of this research include a healthier citizenry. This would be a population that has a sufficient, nutrient-dense, varied, and safe food supply, with less morbidity and decreased health care costs. These traits translate into improved quality of life and worker productivity.

The impact of the research in this area may possibly redefine the nature of the eating experience because food would become a key part of health maintenance. This will result in considerable savings in total health costs.

Investing in food safety research will have substantial financial benefits. Food-borne illness from only seven of the major pathogens is estimated to cost \$6.6 billion to \$37.1 billion annually in medical expenses and lost productivity, according to USDA's Economic Research Service. Food-borne illnesses attributed to meat and poultry alone account for \$5.2 billion to \$28.3 billion. Developing methods to prevent food-borne illness could provide a significant return on research investments.

Detailed knowledge of food safety risks will lead to improved control techniques that can be cost-effectively applied at the appropriate points in the food supply chain. Alternative processes to reduce pathogens are especially needed for foods that are minimally processed or not suitable for heat treatments.

The food supply is vulnerable to deliberate contamination (i.e., bio-terrorism) as well as accidental contamination. Most food safety research findings will apply to both scenarios, although the potential devastation and level of fear associated with terrorist acts magnify the perceived differences. Research leading to the development and use of innovative, secure packaging systems may reduce the likelihood of post-production tampering. Innovative detection methods may reduce the time required to identify the presence of a pathogen or contaminant and, subsequently, reduce the number of people exposed by allowing faster removal of tainted product from the marketplace.

Efforts to mitigate food-safety risk can be successful. In the United States, active surveillance of food-borne listeriosis, followed by control measures initiated in 1989, reduced mortality from this illness by 48 percent by 1993. Continued efforts to apply appropriate technologies at suitable points in the food chain must be based on knowledge gathered through food-safety surveillance and research.

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Appendix 1

TASK FORCE MEMBERS

Colin Kaltenbach (AZ), Chair, *Research management*
David R. MacKenzie (ED/NE),Vice Chair, *Research management*
R. James Cook (WA), *Plant biotechnology and cropping systems*
Sam Donald (ED/1890), *Research management*
Terry Etherton (PA), *Animal nutrition*
Mike Harrington (ED/W), *Research management*
Bob Heil (ED/W), *Research management*
Tom Helms (ED/S), *Research management*
Donna Hess (SD), *Rural Sociology (including biotech socio-econ. and educational issues)*
Kyle Hoagland (NE), *Liminology (including water quality and ecotoxiocology)*
Linda Kinkel (MN), *Plant pathology*
Carol Lammi-Keefe (CT), *Nutrition and development (fetal and neonatal)*
Brian Larkins (AZ), *Plant molecular biology*
Daryl Lund (ED/NC), *Research management*
Thomas A. Lyson (NY), *Rural sociology (including rural development)*
James Marsden (KS), *Meat and food safety*
John E. Mullet (TX), *Crop biotechnology*
Sunil K. Pancholy (FL), *Research management*
Joe M. Regenstein (NY), *Food safety*
Larry Reynolds (ND), *Reproductive physiology (livestock)*
Stephen Rieling (ME), *Economics; research management*
Michael Thompson (IA), *Soil science (including C-sequestration and global warming)*
Richard D. Vierstra (WI), *Plant molecular biology*
Robert P. Wilson (MS), *Biochemistry and molecular biology*

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Glossary

A

Agroforestry Intensive land management practices that combine trees with agricultural crops and/or livestock, including integrated plantings of long-term tree crops with annual crops, trees planted between streams, and annually cultivated crop land or pasture, trees planted in pastures, and tree windbreaks.

B

Bio-based economy The portion of the production, processing, distribution, and consumption of goods and services that are contributed to the economy by living processes.

Bio-based product Something produced using living processes. (See Bio-product)

Biodiversity The many different species of organism and the genetic diversity within a single species.

Bioextraction Methods used to withdraw components of a material (usually selectively) using biological processes.

Biofiltering To remove specific components of a material by means of biological processes.

Biogas A gaseous fluid produced from biological materials, such as methane.

Bioinformatics The branch of information technology that organizes, stores, and retrieves biological knowledge and data.

Biomass A quantitative measure of the amount of biological material.

Biophysical Everything biological that is measurable by weight, motion, and resistance; i.e., the physical sciences component of biology.

Bioremediation Correction of an existing condition using biological processes, such as the clean up of oil spills using bacteria (see Phytoremediation).

Bioproduct Something produced using living processes. (See Bio-based product)

Byproduct Something produced (such as in manufacturing) that is in addition to the principal product.

Biosolid The non-liquid portion of biological wastes.

D

Designer food Any food that has been manipulated by people to serve a particular purpose such as taste or color.

DNA sequenced Determining the order of the genetic code on an organism.

E

Ecosystem The complex of physical, chemical, and biological components (including air, water, soil, climate, and organisms) that sustain living communities of plants, animals, and microorganisms.

Enzymatic conversion The act or process of converting materials using complex proteins that catalyze specific biochemical reactions.

Ergonomics Relating to the study of the work capacity of muscle.

Experimental biology The branch of science that develops knowledge through experiments on living organisms.

F

Functional foods Processed foods and beverages (also sometimes natural foods) promoted and consumed for their medicinal properties beyond just the supply of nutrients to meet body's requirements. These may be natural, engineered, or bioengineered foods, that protect against specific cancers—for example, lycopene for prostate cancer.

G

Gene therapy Remedial treatment of any genetic material, particularly genes associated with a genetic disorder.

Genomics The study of the study of all the genes of an organism.

Germ plasm The hereditary material of germ cells and their precursors.

I

Industrial feedstock Material furnished as input to industrial processes or operations.

M

Metabolic pathways The sequence of enzyme-catalyzed reactions by which an energy-yielding substance is utilized by protoplasm.

Microbial genomics The branch of biology that deals with the heredity and variation of microorganisms and, in recent years, with the nature and function of their genes.

N

Neoclassic economics Contemporary adaptations of classical economic science.

Nutriceuticals Foods that deliver materials that have a pharmacological effect on humans; i.e., foods that are or can substitute for drugs.

O

Open-field burning The practice of burning agricultural areas, oftentimes with the intention of controlling plant pathogens, enhancing plant growth, or stimulating seed production.

P

Pathogenesis The origination and development of a disease.

Peri-urban Area surrounding an urban center often devoted to supplying goods and services to those urban areas.

Petrochemicals Substances produced using fossil fuels (e.g., oil, coal).

Pharm foods A play on words (i.e., "farm food") referring to foods that deliver additional health, safety, or nutritional benefits. (See Functional food)

Phytoremediation Using plants (sometimes in combination with microorganisms) to extract or to stabilize pollutants such as metals, excessive nutrients, or organic compounds in contaminated soil, water, or air (see Bioremediation).

Point and non-point source pollution Classification of the origins of pollutants into those that emanate from a well-defined source (point source) and those that have origins in broad areas (non-point source). An example of point source pollutants would be a chemical dump. An example of a non-point source pollutant would be the unintended consequences of spreading manure on croplands.

Probiotics A substance that enhances growth or promotes health. Antonym: antibiotic.

Proteomics The study of proteins.

S

Socioeconomic sciences The study of the interface of societies and economies

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