Food Safety Science White Paper
U.S. Department of Agriculture
Research, Education and Economics
Office of the Chief Scientist
July 24, 2012

Food safety and the related issue of food protection continues to be a public health priority that requires extensive research, education, and extension efforts focused on the prevention of foodborne outbreaks. This continued priority is in part due to that fact that the production, processing and distribution system for food in and for the U.S. is a diverse, extensive, and easily accessible system. Such an open system is vulnerable to the introduction of contaminants through natural processes, global commerce, and by intentional means. The reduction and control of foodborne pathogens, toxins, and chemicals in the food supply are not possible with a single strategy but rather through concomitant efforts along the food production chain.

The Current State of the Science

Identifying and conducting research, education, and outreach activities necessary for effectively reducing foodborne illness is a challenging and constant undertaking due to the complexity and continual evolution of food production and processing practices, food distribution, consumer preferences and activities, and foodborne hazards. Attempts at measuring the impact of foodborne illness both domestically and internationally can be difficult, with disparate results. And as several recent scientific reports illustrate, while many food safety issues persist, new challenges also arise.

In the U.S., it has been difficult to estimate the number of foodborne illnesses and consequently the burden on society. CDC now estimates that 47.8 million illnesses and 3,037 deaths were caused by contaminated food consumed in the U.S. (Scallan et al., 2011a; Scallan et al., 2011b; Mead, 1999). Although this recent data indicates lower numbers of cases than their previous estimates, we are cautioned that these estimates cannot be compared with those of 1999 because of changes in data sources and methods. Estimates of the economic burden of foodborne illness are also subject to uncertainty. Batz, Hoffmann, and Morris (2011) estimate the annual cost of fourteen pathogens at $14 billion/year. These fourteen pathogens represent over 95 percent of the annual illnesses and hospitalizations, and almost 98 percent of the deaths, estimated by CDC to be due to the 31 foodborne pathogens identified in Scallan et al. (2011a). Of these fourteen, 90 percent of the economic cost is due to five pathogens: *Salmonella*, *Campylobacter*, *Listeria monocytogenes*, *Toxoplasma gondii*, and norovirus. There are almost no foodborne diseases registries in the U.S. that would enable long-term follow up on patients who have suffered from foodborne illness. The estimated burden of foodborne illness indicates that more effective strategies to increase the safety of food in the U.S. are needed. The best strategies are not limited only to research, but include education and outreach.

U.S. food safety research, education, outreach and subsequent regulation must continue to evolve to address the enormity of foodborne hazard challenges, with accomplishments measured at the public health level. Persistent outbreaks related to major commodity-specific foods that may directly affect public health, regulations, industry, and trade, require immediate attention. More broadly, food and food safety research and policy decisions must be based on a science- and health-based food safety system. Food safety programs constructed around public health include foodborne diseases outbreaks and chronic sequelae, but also broader thinking about future

potential threats before they impact the food supply, and how food affects the health of its consumers. Because 75% of the foodborne diseases are zoonotic (transmitted from animals to humans), cooperation between animal and human health scientists is necessary to explore possible new foodborne zoonotic pathogen threats and to be aware that immune-suppressed populations may be a higher risk for zoonotic disease.

Several significant reports in the last 15 years have focused on the need for a science-based and public health-focused food safety system. The 2003 Institute of Medicine (IOM) report "Scientific Criteria to Ensure Safe Food" provided pivotal new recommendations on developing science-based food safety criteria that would be linked to public health objectives (Institute of Medicine, 2003). This report was unique in outlining specific criteria that could be defined at each phase of production. The microbiological criterion, for example, defines the acceptability of a product or food lot, based on the number (or presence or absence) of microorganisms, including their toxins or metabolites, while the food safety provides a way to relate performance standards in food production to public health objectives. The IOM recognized the importance of Hazard Analysis and Critical Control Point (HACCP) principles and "Good Agricultural Practices" being implemented by industry. IOM also recognized that the application of criteria and standards throughout the food continuum would not be easy because of the numerous opportunities for disease causing organisms and chemical contaminants to enter the food supply. Pre- and post-harvest food safety efforts, moreover, have often been handled independent of one another. The IOM noted further that the food safety regulatory framework is fragmented among different regulatory agencies and different stages of food production. The 1998 IOM report "Ensuring Food Safety from Production to Consumption" previously reported on the fragmentation of food safety not only in regulatory statutes but also in regards to surveillance, public perception, and research.

More than twelve years after the 1998 IOM report, the FDA Food Safety Modernization Act was implemented in January 2011. This Act is supported by consumers, public health advocates, and major industry groups as an important advancement for mandatory recall powers and national/international inspections. Although the Act specifically addresses FDA needs and issues, it also tasks the agency to collaborate with other federal agencies to coordinate and improve strategies on prevention, traceability, and accountability, for U.S.-grown and imported foods.

The President's Food Safety Working Group (WG) is another example of collaboration between Federal agencies. USDA and DHHS, along with several partner agencies, make up the WG whose core mission is to strengthen federal efforts and develop strategies to improve food safety. The WG advises the President on the efficacy of U.S. food safety legislation, opportunities for fostering coordination of food safety efforts through the government, and ensuring laws are adequately enforced to keep food safe. The three core guiding principles of the current WG support: 1) outbreak prevention, 2) effective food safety inspections and enforcement, and 3) surveillance of and intervention in outbreaks of foodborne illness. Allied to these core principles is the need to address the science-based national food safety objectives outlined in the Healthy People 2020, a CDC initiative to improve the health of Americans.

Food safety is a growing global concern due to increased international travel and migration, globalization of trade, and social and economic changes. Food safety problems extend across a diversity of food systems in developed and developing countries, including a broad range of foodborne contaminants. In May 2010, the World Health Assembly re-emphasized their 2002

resolutions: to continue the global strategy for the surveillance of foodborne diseases and for efficient gathering and exchange of information in and between member countries; to continue the recognition of the important role of the Codex Alimentarius Commission; and to promote recent WHO initiatives for the estimation of the burden of foodborne illness and surveillance capacity building (WHO, 2010; WHO, 2002). Similarities in the goals of the U.S. and the WHO provide opportunities for scientific interaction, collaboration among agencies and institutions, and address global concerns on import and export food safety standards. Global partnerships and common standards are increasingly important as the import and export of food increases. During the last 10 years, while the amount of food imported into the U.S. has tripled, only 1-2% is ever physically examined. Justifiably, concern over the safety of imported foods is highlighted in the new FDA Food Safety Modernization Act recently approved by Congress.

The goal for USDA's Research, Education, and Economics (REE) mission area to advance the research, education and extension efforts in food safety is clear. The REE strategy is to advance research, education, and outreach in known, high priority areas of food safety concern. REE agencies work to be responsive to emerging problems and regulatory needs, while maintaining long-term goals. Educational and outreach priorities are coordinated with research activities and needs.

Both the IOM 1998 and 2003 reports identify research, education, and outreach efforts that are still relevant today. Many of these efforts were more recently cited in the 2010 American Academy of Microbiology (AAM) report, "Global Food Safety." Many of these priorities are addressed by USDA science. These goals are a response to the increasing need to understand the behavior and interactions of microbial populations within their ecological niches, with other microbes and foodborne hazards, the environment, and humans. Enhanced technologies and approaches provide new opportunities for identifying emerging pathogens and helping private industry and regulatory bodies identify foodborne hazards.

All food safety research, education, and extension is conducted with the ultimate aim of eliminating pathogens, and other biological and chemical contaminants in foods; consequently, reducing the occurrence of foodborne illnesses. To this end, we have identified two primary goals: prevention and control. These goals are intended to address current problems but also to meet emerging challenges and technologies. For example, climate change not only affects food security, water quality and resources, and crops, but may also influence the emergence of new pathogens or may lead to an increase in aflatoxin levels. The increased use of biotechnology in detection methods (nanotechnology) and in bioengineered crops has raised the awareness of evaluating food safety. These are but two of the many challenge areas in which REE has the potential to make significant advances through research, education and extension efforts.

Current Research Challenges and Proposed Research Program

Vision: Provide science that informs decisions and policies that contribute to a safe food supply and the reduction of foodborne pathogens and other contaminants.

USDA's Research, Education, and Economics agencies are uniquely positioned to contribute science-based information to public health decisionmaking and agricultural policymaking that

will ultimately help to reduce foodborne pathogens and other contaminants. Each agency contributes unique expertise and roles. The Agricultural Research Service (ARS) provides the research infrastructure and expertise to address short and long-term needs in food safety. Because of its federally-operated infrastructure, ARS is able to respond quickly to emerging and critical food safety issues. At the same time, this well-established research program provides food safety research assistance to regulatory agencies, private industry, and international collaborators. (http://www.ars.usda.gov/research/programs/programs.htm?NP_CODE=108).

The Economic Research Service (ERS) has a unique capacity to assess potential and real costs and benefits of foodborne illness outbreaks and food safety programs throughout the supply chain. ERS economists were the first to estimate the costs of foodborne illness, and continue to update these estimates in collaboration with CDC. ERS economists address food safety management questions from the farm, through processing, all the way to food retailing and consumer response to recalls. This integrated approach facilitates unique and important research to identify the most efficient mechanisms for food safety improvement. (http://www.ers.usda.gov).

With a mission to collect and analyze survey and field data to better understand agriculture's role in food safety, the National Agricultural Statistics Service (NASS) plays a unique role within USDA. The agency collects data from agricultural operations and agri-business, and collects corollary data providing context to the extent, impact, source, or spread of agricultural products. (http://www.nass.usda.gov).

The National Institute of Food and Agriculture (NIFA) funds research, education, and extension at the state and local levels and provides program leadership in these areas. Food safety-related grant programs include the Agriculture and Food Research Initiative, National Integrated Food Safety Initiative, Specialty Crops Research Initiative, and Small Business Innovation Research (SBIR). Formula grant programs include Hatch, Evans-Allen and Science and Education Resources Development. Each program has a slightly different focus but they are complementary. NIFA promotes and enhances the scientific disciplines of food safety through these extramural grants with the overall focus of protecting consumers from microbial and chemical contaminants that may occur during all stages of the food chain, from production to consumption. (http://www.nifa.usda.gov).

As food safety knowledge and activities have evolved, REE's goals have evolved as well. The research goals across these agencies provide both broad and focused approaches for research, education, and extension activities in food safety. The range that they span provides the opportunity to develop research applicable to addressing current recognized foodborne pathogenic and contaminant threats, while also providing the framework for research, education, and extension activities to address long-term, as well as just emerging needs**.** As technologies and methods evolve, new pathogens are often identified. Examples of salient emerging issues of concern include produce food safety, the detection and characterization of chemical (or bio-threat) contaminants, the potential effects from climate change on food safety, and the development and evaluation of prevention and intervention strategies along the food continuum. Coordination among the REE agencies is critical to help provide food safety knowledge and solutions, and will be addressed through the following strategies:

1. Providing research that helps define and explain the microbial populations (pathogens and normal flora) in foods and surrounding environments.
2. Providing research to aid understandings of the biology and behavior of foodborne pathogens.
3. Developing technologies for the detection and characterization of food supply contamination from microbial pathogens, toxins, chemicals, and biologics.
4. Developing intervention and control strategies for potential foodborne contaminants along the food production continuum.
5. Developing, providing, and evaluating analytical and statistical methods that will help in the measurement and evaluation of foodborne pathogens and contaminants, pathogen load, the economic cost and burden of foodborne illness, and public health risk.
6. Providing research strategies, models, and data that identify and characterize effective management strategies and incentives for food safety improvement and the costs and benefits of improved safety for public health and industry viability.

Strategy 1: Provide research that helps define and explain the microbial populations (pathogens and normal flora) in foods and surrounding environments.

Current USDA Science:

This objective unifies pre-and post-harvest food safety into a single entity, as it identifies and characterizes the movement, structure, and dynamics of microbial populations throughout food production and processing; hence, across the entire continuum. At the microbial level, the diversity and complexity within environments and food matrices may change with spatial and temporal influences, or with the competitive or synergistic relationships among pathogens and commensals. Environmental factors may determine the conditions under which particular microorganisms exist, and microorganisms may in turn influence the conditions prevailing in the microbial and surrounding environment. Currently, each REE agency is contributing to this strategic area. The following are examples of REE strengths:

- Leading the epidemiologic and ecologic long term population study of produce in California. This research helped find solutions to the causes of many recent produce associated foodborne outbreaks. (ARS)
- Maintenance of a network of experts and facilities for defining microbial populations in waterways and soils, and determining how these factors affect the production of produce and potential public health risks. (ARS)
- Maintenance of a network of scientists and facilities evaluating both pre- and post-harvest interventions for the most common foodborne pathogens in multiple food animal species. (ARS)
- Examination of how consumers respond when Federal health and safety officials inform them about the safety of particular foods. (ERS)
- Administration of extramural grants in food safety and related topics. This research portfolio includes research on monitoring, surveillance, and control of microbial pathogens, chemicals, toxins, and nanoparticles in food and the environment (pre- and post-harvest environments). (NIFA)

Primary Goals:
To provide data that will enhance our knowledge of the interaction among foodborne pathogens and contaminants, foods, hosts, and the environment. This knowledge will help in the design and implementation of potential control and intervention strategies. The principal focus is addressing microbial pathogens, and to a lesser extent biological (toxins) and chemical (residues) contaminants.

Anticipated Outcomes:

- The development of approaches/designs for both microbial and population-based studies, monitoring of known and emerging foodborne pathogens, biological and chemical contaminants, and the provision of data for identified data gaps. (ARS, NIFA)
- Determination of the role/effect of transportation, lairage, slaughter, harvesting, processing, storage, environment, and equipment on foodborne hazard fate and transfer. (ARS, NIFA)
- The development of approaches/designs for the analysis and interpretation of complex data. (ARS, ERS, NIFA)

Strategy 2: Provide research to understand the biology and behavior of foodborne pathogens and biological and chemical contaminants.

Current USDA Science:

Various technologies must be used to understand the complex biological interactions in foodborne pathogens. It is appropriate to employ the concept of "systems biology" involving an integrated, systematic, and trans-disciplinary approach combining microbiology, genomics, proteomics, other "omics," and bioinformatics. Included within this area is pathogenicity and virulence. Understanding pathogenicity is critical for pathogen intervention and control, modeling, and for providing data for the development of risk assessments by regulatory agencies. Pathogens have the capacity to readily and rapidly adapt and evolve, or arise from new origins. Implemented control strategies may accordingly lose effectiveness, demanding the development of new production processes and products to maintain and improve food safety. Effective risk assessments conducted by regulatory agencies are dependent upon proper understandings of pathogen behavior, dose response, activity in foods, and influences that may positively or negatively affect virulence. Assessing the virulence of foodborne organisms and differences among serotypes is critical in implementing new surveillance and intervention strategies. The following are examples of REE agency strengths and resources:

- A dedicated program that examines the behavior of microorganisms in foods. The Pathogen Modeling Program (PMP) works to predict the growth and activity of foodborne bacteria under various environmental conditions. Since the early 1990s, PMP data has been distributed in spreadsheets, stand-alone software, and now online. (ARS)
- Developed in association with other international organizations, "ComBase" is a database containing information about how microorganisms respond to different environments. The goals of ComBase are to improve efficiency in locating microbiological information; to provide a means to compare data; and to reduce redundancy in conducting microbiological studies. (ARS)

- The USDA extramural research portfolio includes competitive grants that investigate the microbial ecology of foodborne pathogens in animals, soil, water, and on food surfaces. Research also includes mechanisms for the attachment, internalization and migration of foodborne hazards into plant tissues, and their interaction with microorganisms. (NIFA)

Primary Goals:

Provide data that will help in understanding the biology and behavior of foodborne pathogens, including contaminants such as chemicals and toxins. These data can help support risk assessments, contribute to validation processes, and lead to better control and intervention methods.

Anticipated Outcomes:

- The development of a comprehensive microbial database containing molecular, physiological, and genetic data on each known foodborne pathogen and its niche. (ARS)
- The development of model systems that can be used in risk assessment. (ARS, NIFA)
- The development of approaches/designs for the analysis and interpretation of complex data. (ARS, NIFA)
- The identification of control and mitigation strategies that limit foodborne hazard contamination of fresh produce. (ARS, NIFA).

Strategy 3: Develop technologies for the detection and characterization of food supply contamination from microbial pathogens, toxins, chemicals, and biologics.

Current USDA Science:

Challenges occur when either microbes or other contaminants enter the food supply through raw materials or via contamination during processing. Therefore, detection and characterization is required at the earliest possible stage in the food chain, providing the necessary data for targeted interventions and reducing the need for recall of food products from purchase endpoints. Where possible, technologies must be developed for the entire food chain which allow the most effective, data-driven, and rapid detection and characterization (e.g. determination of viability and infectivity) capabilities. Effective research addresses specific stakeholder needs, focusing on the most promising technologies, point of use, and specifying technology for baseline studies, real-time control, traceability and/or forensics. This requirement means that decisions must be made relative to what should be detected, and the required level of detection and characterization. It also means that technologies with the highest level of detection/characterization capability might not always be the most practical, useful, or economically viable for particular objectives. The following are examples of REE agency strengths:

- The Research Center at Fargo, ND is the only USDA laboratory with the ability to conduct research and analysis on the prevalence of dioxins in food animals and foods. This laboratory conducts the national dioxin studies for USDA's Food Safety and Inspection Service. (ARS)

- The Research Center at Wyndmoor, PA, is the only USDA laboratory that develops detection technologies for chemical contaminants, e.g. pesticides, hormones, antibiotics in foods. (ARS)
- The Research Centers at Athens, GA and Beltsville, MD are the only USDA laboratories that develop sensing technologies and approaches that enable real–time and sensitive detection of foodborne pathogens, and chemical contaminants in and on foods. (ARS)
- The Research Center at Albany, CA is the only USDA laboratory with the expertise for the development of methods and technologies to detect biosecurity agents in food matrices. These technologies are used by USDA, DHHS (FDA/CDC), the Department Homeland Security (DHS), and the U.S. military. (ARS)
- The Research Center at Peoria, IL is the only USDA laboratory with the expertise and capability to detect and characterize mycotoxins that pose a public health risk. (ARS)
- The USDA extramural research portfolio includes a focus on the development and testing of detection methods for field use in a variety of settings. Recent programs solicited research on the development of and testing for foodborne viruses, E. coli, Salmonella, and Campylobacter, and other pathogens. (NIFA)

Primary Goals:

Develop detection technologies for foodborne pathogens and contaminants. These technologies can be transferred to other regulatory agencies and industry for implementation that could lead to the reduction or elimination of foodborne pathogens or contaminants. Technologies for the characterization of existing and emerging pathogens, toxins, chemicals, and biologics will provide important data for developing future recommendations and activities.

Anticipated Outcomes:

- The development of specialized technologies to differentiate pathogenic from non-pathogenic strains, and to elucidate the differences (ARS, NIFA).
- The development of detection technologies for emerging or multiple microbial pathogens that are cost effective and provide the required information for implementation (ARS, NIFA).
- The development of technologies for the rapid and sensitive detection of toxins, chemicals, and biologics that can be implemented for improved food safety and food defense (ARS, NIFA)
- The development of multi-task, real-time, on/in-line inspection technologies that detect contaminants and quality attributes simultaneously at required line speeds (ARS).

Strategy 4: Develop intervention and control strategies for foodborne hazards along the food production continuum.

Current USDA Science:

Intervention and control strategies help to significantly decrease or eliminate foodborne contaminants in food animals and their derived products, seafood, and plant crops during critical periods of production and processing. Reduced shedding of zoonotic pathogens by food

producing animals and contamination of seafood and plant material helps reduce the pathogen load during slaughter/harvesting, and subsequent processing and storage. In the past 15 years, there has been a greater focus on plant food safety, since fresh produce has become a common source of foodborne illness. This attention provides an opportunity to strengthen and increase research specifically addressing produce needs. Many food processing/storage technologies have the ability to inactivate microorganisms to varying degrees; however, the intensities required can result in adverse functional and/or sensory properties, and significant reduction in quality. Consequently, there is a continued need to develop and subsequently combine new/innovative processing technologies. The following are examples of REE strengths:

- The intramural and extramural research portfolio includes development and validation of pre- and post-harvest intervention and control strategies for multiple microbial pathogens and their numerous serotypes in various food animals, plants (produce), and seafood. The research addresses industry and regulatory agency needs. These projects include education and/or extension efforts. (ARS, NIFA)
- The development of improved production techniques to address problems in commercial biological control practices and increase efficacy against mycotoxin producing fungi, including the understanding of the genetics of mycotoxin production through an examination of the population dynamics of toxigenic fungi. (ARS)
- Research that develops, evaluates, and validates new approaches for regulatory monitoring of chemical residues in foods and feed. (ARS)
- The provision of toxicological data and development and validation of analytical methodology for the detection of microbial toxins in food and feed. (ARS)

Primary Goals:

To develop intervention and control strategies for foodborne pathogens and contaminants, including chemicals, toxins, and biologics that can be implemented along the food production continuum where appropriate. To evaluate the impact of these interventions and control measures on pathogen load and potential foodborne disease risk.

Anticipated Outcomes:

- The development of approaches that evaluate and validate the impact of intervention/management strategies on contamination in the food continuum. This includes organic, conventional, and other production systems at all levels (small, medium and large operations) as well as alternative harvest, processing, and marketing methods. (ARS, NIFA)
- The development of technologies for assessing the efficacy of various processing methods to reduce or eliminate contaminants in foods for human/animal consumption. (ARS, NIFA).

Strategy 5: Develop, provide, and evaluate analytical and statistical methods that will help in the measurement and evaluation of foodborne pathogens and contaminants, pathogen load, the economic cost and burden of foodborne illness, and public health risk.

Current USDA Science:

Research is still evolving in the area of analytical and statistical methods to quantify foodborne "risk" from pre-harvest, through processing, to the consumer. Measurements at the pre-harvest level include prevalence or number of organisms shed or other contaminants at the animal or farm level. Verification testing in processing plants or research studies quantifying pathogen prevalence provide potential data regarding risk. It is currently difficult to correlate these data with the prevalence of foodborne disease or public health risk. The IOM (2003) report outlines specific microbiologic criteria, performance standards, food safety criteria, and public health objectives that producers, scientists, and regulators can strive to measure and implement. Currently, the two major food safety regulatory agencies, USDA's Food Safety and Inspection Service (FSIS) and FDA are looking to other agencies for guidance on analytical and statistical approaches for qualitative and quantitative measures. This initiative also fits with the President's Food Safety Working Group (WG) goals. REE strengths in this area include:

- Collaboration with CDC on the estimation of foodborne illness and provision of publicly available analyses of the estimations and assumptions. (ERS)
- Collaborations with the WHO on the global burden of disease and the education in laboratory (methods) and epidemiologic capabilities. (ARS, ERS)
- Providing extramural grant support for epidemiologic approaches that help quantify foodborne hazard load from the farm through processing. Explore different approaches to better explain and measure how foodborne hazard load may equate to public health risk. (NIFA)
- Technology development to better characterize and quantify foodborne pathogens and contaminants along the food chain, used in risk assessments for public health risk. (ARS)

Primary Goals:

Develop research, education, and extension efforts that will aid in the understanding of the quality and quantity of foodborne contamination and foodborne disease. Outline potential collaborations and studies that could better characterize and define pathogen load, foodborne disease, and public health risk.

Anticipated Outcomes:

- Provide burden of foodborne illness estimates for medical costs, loss of productivity and other outcomes in collaboration with public health agencies, like CDC and WHO. (ERS)
- The development of intramural and extramural research directions that aid understandings of risk-based standards, metrics, and the impact of interventions and control strategies. (ARS, NIFA)
- The development of education and extension efforts capable of enhancing analytical and statistical methods (such as epidemiology, bioinformatics, geographical information systems, and meta-analysis). (NIFA)

Strategy 6: Provide research strategies, models, and data that identify and characterize effective management strategies and incentives for food safety improvement and the costs and benefits of improved safety for public health and industry viability.

Current USDA Science:

One area of focus is estimating the costs of foodborne illness to help policymakers rank risks, focus policy, and prioritize spending. Research is needed to show how use of product testing, food safety equipment, sanitation practices and other food safety technologies vary by plant size, production characteristics, and how the choice of technology is affected by third party audits and other contracting mechanisms. This research will identify gaps in food safety management that can be addressed by new technologies. Research is needed to identify cost effective farm and processing strategies which focus on the prevention of contamination and demonstrate economic trade-offs associated with preventing contamination before it happens. Expertise in data collection and survey implementation (NASS) provides an opportunity to update and extend economic implementation burden estimates for industry, from farm to processing plants. The following are examples of REE strengths:

- Estimation of the economic burden of foodborne illness and potential contamination events due to medical costs, productivity losses, and premature deaths, and long-term outcomes (such as reactive arthritis, neurologic and kidney damage, and yet unknown consequences). Updating these estimates in collaboration with CDC and providing publicly available analysis of how such estimates vary with different assumptions. Evaluation of macro- and microeconomic effects (from reduction in GDP in absolute or growth rate to the firm level). (ERS)
- Estimation of how the costs of new meat and poultry regulations vary by plant size and type of production system. Investigation of the incentives for improvement in different commodity supply chains to identify best industry practices and potential barriers to improvement. (ERS)
- On-going surveying of farm production practices and costs and returns (ARMS) includes questions addressed to farm-level production practices that can affect food safety. These data support analysis of alternative management strategies for farm level pathogen reduction. (ERS, NASS)
- Examination of how consumers respond when Federal health and safety officials inform them about the safety of particular foods (ERS)
- Collaborations in two WHO initiatives where current REE food safety expertise and research help enhance international efforts. These WHO programs involve the estimation of the global burden of foodborne disease and the training in laboratory and epidemiology capabilities. (ARS, ERS)
- Providing research strategies, models, and data that identify and characterize effective management strategies and incentives for food safety improvement and the costs and benefits of improved safety for public health and industry adoption. (ERS, NIFA)

Primary Goals:

To provide data and strategies which describe the costs, benefits, and effectiveness of research and management strategies that could improve public health and industry viability. This knowledge will help measure the impact and outcome of intervention and control strategies focused on the reduction of foodborne pathogens and contaminants.

Anticipated Outcomes:

- Providing relevant data to regulatory agencies for use in HACCP programs, risk assessments, labeling, persistence, and issues related to international trade. (ARS, ERS)
- The development of the economic models and data to explain how interventions might be adopted and used by various agricultural production systems. (ERS, NASS)
- The development of economically viable control and mitigation strategies taking advantage of environmental, vector and reservoir characteristics (ARS, NIFA, ERS, NASS)
- The identification of incentives for investment in food safety improvements in meat and poultry plants. (ERS, NASS)
- The identification of on-farm food safety practices and incentives.(ERS, NASS)
- Increase understanding of the outcomes from foodborne illness, including severity and medical costs, lost work productivity, and economic consequences of the loss of life. Update and extend economic burden estimates to include their full economic impacts. (ERS)

References:

American Academy of Microbiology (AAM). (2009). *Global Food Safety: Keeping Food Safe from Farm to Table.* Washington, DC: American Academy of Microbiology.

Batz, M. B.**,** Hoffmann, S., & Morris, J. G., Jr. (2011). *Ranking the Risks: The 10 Pathogen-Food Combinations with the Greatest Burden on Public Health*. Emerging Pathogens Institute, University of Florida.

IFT Foundation. (2009). Making decisions about the risks of chemicals in foods with limited scientific information. *Comparative Reviews in Food Science and Food Safety, 8*: 269-303.

Institute of Medicine (IOM). (1998). *Ensuring Safe Food from Product to Consumption.* Washington, DC: National Academy Press.

Institute of Medicine (IOM). (2003). *Scientific Criteria to Ensure Safe Food.* Washington, DC: National Academy Press.

National Advisory Committee on Microbial Criteria for Foods (NACMCF). (1998). Hazard Analysis and Critical Control Point Principles and Application Guidelines. *Journal of Food Protection 61*(9), 1246-1259.

Mead, P. S., Slutsker, L., Dietz, V., McCaig, L. F., Bresee, J. S., Shapiro, C., & Tauxe, R. (1999). Food-related illness and death in the United States. *Emerging Infectious Diseases, 5:* 607-25.

Scallan, E, Griffin, P. M., Angulo, F., Tauxe, R., & Hoekstra, R. (2011a). Foodborne Illness Acquired in the United States-Unspecified Agents. *Emerging Infectious Diseases, 17*(1), 16-22.

Scallan, E., Hoekstra, R., Angulo, F., Tauxe, R. V., Widdowson, M., Roy, S. L., Jones, J. L., & Griffin, P. M. (2011b). Foodborne Illness Acquired in the United States- Major Pathogens. *Emerging Infectious Diseases, 17*(1), 7-15.

World Health Organization (WHO). (2002). *Global Strategy for Food Safety*. Geneva, Switzerland: Author. Retrieved from http://www.who.int/foodsafety/publications/general/global_strategy/en

World Health Organization (WHO). (2010). *Advancing Food Safety Initiatives*. Resolution from the 63rd World Health Assembly to update the Global Strategy for Food Safety. Retrieved from http://apps.who.int/gb/ebwha/pdf_files/WHA63/A63_R3-en.pdf