Action Plan
National Program 101
Food Animal Production
2013-2018

Vision Statement:
The vision for National Program 101 is to furnish the scientific community and the food animal industries with scientific information, biotechnologies, and best management practices that ensure consumers an abundant supply of competitively priced animal products which enhance human health, ensure domestic food security and enhance the efficiency, competitiveness and economic and environmental sustainability, of the food animal industries.

Mission Statement:
To foster an abundant, safe, wholesome and competitively priced supply of animal products produced in a viable, competitive, and sustainable animal agriculture sector of the U.S. economy, the mission of the Food Animal Production Program is to:

1) Safeguard and utilize animal genetic resources, associated genetic and genomic databases, and bioinformatic tools;

2) Develop a basic understanding of food animal physiology for food animal industry priority issues in animal production, animal well-being, and product quality and healthfulness; and

3) Develop information, best management practices, tools, and technologies that can be used to improve animal production systems, enhance human health and ensure domestic food security.

Strategic Objectives:
The food animal national program has six strategic objectives:

1. Facilitate highly effective comprehensive research collaborations with ARS laboratories, food animal industry stakeholders, academia and other federal agencies to best leverage resources and expertise for maximum industry value and impact.
2. Foster academic growth and individual leadership in NP101 to enhance or create awareness of ARS scientific accomplishment and impact with other agencies, academia and industry stakeholders.
3. Ensure access to specialized genome sequencing and related technologies and bioinformatic resources and infrastructure for all NP101 research communities.
4. Develop an integrated collaborative animal and microbial genomics research program.

5. Provide science based industry relevant solutions in food animal nutrition, reproduction, animal breeding and genetics, animal well-being and product quality.
6. Develop a model technology transfer program to achieve the full value and impact of NP101 research for the food animal industries.

Background

Food animal production and product consumption is increasing significantly around the world as consumers seek higher quality and more nutrient dense sources of protein, iron and other vital nutrients. This trend will continue as the world's population continues to grow and as animal production systems increase efficiencies across varied environments and production systems. Animal production systems fit a unique and valuable niche in the global food production equation by utilizing feeds and forages not appropriate for human consumption. Animal production will continue to serve in this vital role in human nutrition and in environmentally sustainable food production systems across the globe.

The United States has historically been a leading source of quality animal products and has led the world in technological development and adoption. These advances have enabled the United States to develop one of the most efficient animal production systems on earth and the U.S. Department of Agriculture Agricultural Research Service (USDA/ARS) has been a vital part of that achievement. However, agriculture is being relied on to provide for a growing world population more now than at any other time in modern history. Pressure to feed a projected nine billion people by 2050 make the role of the USDA/ARS critically important and underscores the importance of the recent retrospective review of National Program 101 (NP101) and the subsequent 5 year program planning process. To remain competitive in the face of extraordinary growth in animal production systems around the world, the animal industries in the United States must continue to focus on increasing production efficiencies through the development and adoption of scientific technologies. The application of new tools in genomics, metagenomics, reproductive physiology, nutrition, and molecular biology in concert with animal health and in support of traditional husbandry, animal welfare and ecosystem services will continue to improve the long tradition of global economic competitiveness and sustainability of U.S. food animal production.

U.S. systems of agricultural animal management and production face formidable challenges. One of the most exacting challenges is successful adaptation to the accelerating demands of society that impact animal productivity and product quality. The demands placed on the national system of food animal production by a rapidly changing world, for example increasing population, rising obesity, demands for better nutrition and lower costs, can only be met by technologies that optimally harness the inherent genetic potential of animal and plant germplasm in concert with certified industry and food marketing practices. Production systems that successfully identify, preserve, and harness

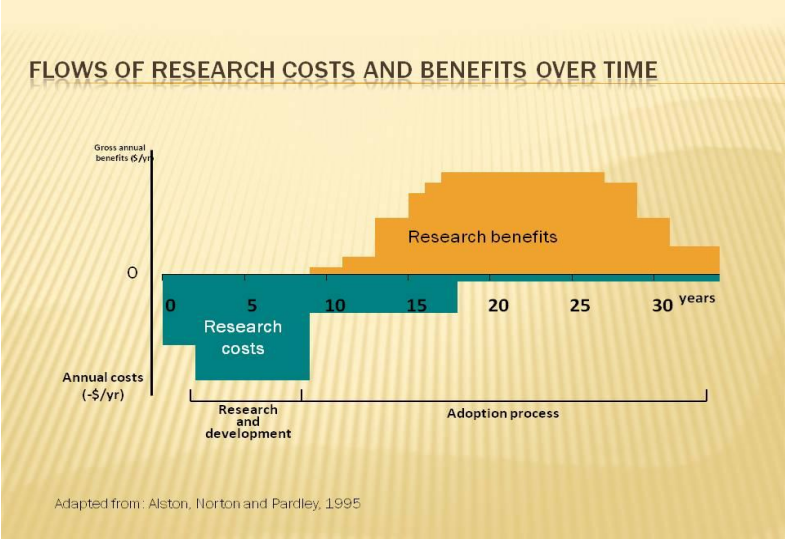
that genetic potential will maximize profits, secure supply, increase market competitiveness, sustain small and mid-sized producers, and maintain genetic diversity and consumer confidence.

Unfortunately, the USDA-ARS NP101 does not have the resources or scope to address all valid researchable priorities for the livestock production industries in the United States or internationally, so consequently must concentrate in areas where maximum impact is possible. While these limitations may restrict the overall scope of the research in NP101, the current priorities and focus of the research in NP101 have produced extraordinary results for the livestock industries in the US and internationally in specific areas of focus. ARS research in NP101 directly impacts production livestock agriculture across species and around the world in genetics, reproduction, nutrition, animal well-being and product quality.

According to the USDA-Economic Research Service, agricultural research has historically produced remarkable rates of societal return on investment with estimates ranging from 20% to 60% annually. In other words, for every $1 invested in agricultural research $5 to as much as $20 is returned to the economy in present value. A specific focus on industry priorities has allowed NP101 to produce returns estimated to be well within this range and the current advancement of genomic technologies will increase the impact of the program even further. Much of the current research in NP101 is just beginning to engage genomic technologies and the opportunities they provide to accelerate scientific discovery.

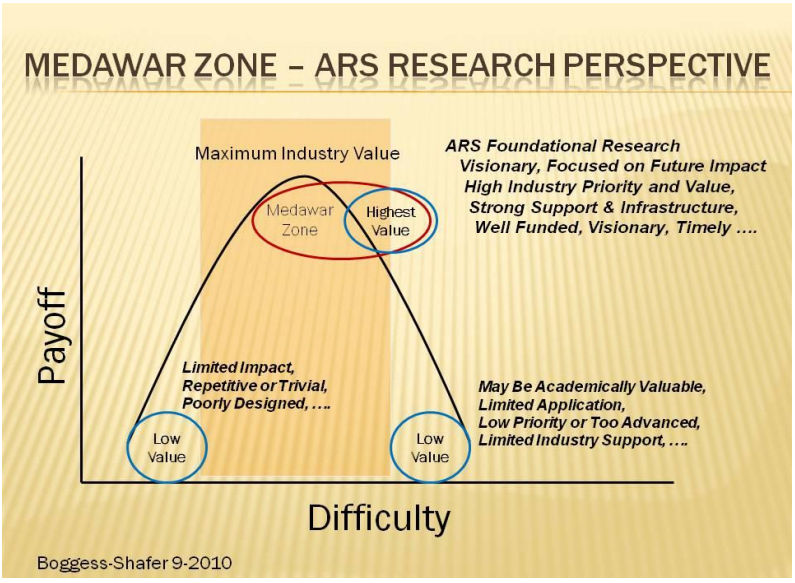
It is important to consider that the value of applied and translational research is not typically maximized without prior basic research to set the foundation and identify scientific priority and opportunity. Both are critical to deliver the ultimate promise and value of research. There can be little truly valuable applied research without strong basic research and neither applied nor basic research is of value if the technologies developed are never applied successfully in the field. Basic discovery science is often more difficult, longer term and with additional inherent risk than applied or translational research. However, basic discovery science provides the opportunity to realize extraordinary scientific benefit, ultimately through applied and translational research, by providing the foundation and vehicle for scientific discovery and eventual application. That is one of the primary tenets of USDA/ARS and NP101 research and will continue to underpin the research programs. The following graphics illustrate these points.

Figure 1: Flow of resources, research benefits and research costs for public research



This graphic developed by Alston et al., 1995, illustrates the flows of resources, research benefits, and research costs for public research in agriculture. It shows clearly the challenge of basic discovery science in that while the benefit is often extraordinary, as reflected in the estimated value of the return on investment for public research of 20 to 60% annually, the benefits are typically not realized for many years after the research has been completed. This dichotomy – the time between discovery and application – jeopardizes the long term support and commitment required to realize maximum benefit, unless the funding entities and stakeholders clearly understand the critical need for long term sustained support and investment in basic discovery science.

Figure 2: Optimizing the focus and timing of basic discovery science



This illustration adapted from Loehe illustrates the principal of the **Medawar Zone** where the area of scientific discovery is most likely to produce maximum benefit. Research that is trivial, repetitive or overly simple is unlikely to produce novel or significant results. Research that is too ambitious, purely academic or not adequately developed scientifically may not succeed at all, may be rejected by the research community at large or may be irrelevant to industry stakeholders. The challenge for USDA/ARS and National Program 101 is to focus scientific discovery in the Medawar Zone or the area where maximum societal value is realized by the research, and to avoid trivial repetitive research as well as research that may be academically valuable but is poorly timed or has no ultimate scientific utility or value to industry stakeholders. This challenge again underscores the need for long term sustained funding, strong visionary leadership and stakeholder commitment to ensure the value and impact of research in National Program 101.

Finally, research in NP101 continues to increase in scientific complexity as the most valuable and impactful challenges to the livestock industries are addressed. Challenges characterized as having maximum industry priority and value are well represented in Figure 2 at the top of the Medawar Zone and in the case of the USDA/ARS and NP101 to the right of the Medawar Zone peak as scientific discovery progresses over time. These challenges are not simple. They require strong research programs with visionary and long term commitment, multidisciplinary collaborations, strong leadership and strong industry stakeholder support. These challenges now typify much of the research undertaken by scientists in National Program 101. New models for research program development and implementation in National Program 101 are being developed across USDA/ARS program, Land Grant Universities and industry collaborators to best address the complex challenges facing the research community in National Program 101.

The USDA/ARS has the national capability and demonstrated performance to lead U.S. food animal research and technology development to enhance the sustainable and economically viable production of food animal products in the United States. USDA/ARS and partners conduct a food animal research program that has contributed significantly to national growth and global competitiveness of the U.S. production industries. A strong USDA commitment to food animal production research, technology development, and technology transfer through ARS and the National Institute for Food and Agriculture (NIFA) in cooperation with university and private research programs, and linked to State and regional agricultural extension programs, is critical to energize industry development, improve production efficiency, and assure quality and wholesomeness of food animal products.

The Agricultural Research Service (ARS) is the intramural research agency for the U.S. Department of Agriculture (USDA), and is one of four agencies that make up the Research, Education, and Economics mission area of the department. The ARS budget is

allocated to research conducted in 22 national program areas. Research is conducted in 108 laboratories by ~2,200 full-time scientists within a total workforce of ~8,000 ARS employees. The ARS national program addressing animal production is NP 101 – Food Animal Production. NP 101 involves research conducted at 20 U.S. locations by 102 full-time scientists and has an appropriated budget of approximately $46.5 million per annum.

Relationship of This National Program to the 2012-2017 USDA/ARS Strategic Plan

The NP101 Action Plan addresses the high level goals and objectives of the **USDA 2012-2017 Strategic Plan**, found in **Strategic Area 4: Animal Production and Protection**. Specific Goals and Performance Measures for NP101 are:

Goal 4.1: Provide scientific information and biotechnologies to enhance management practices that will ensure an abundant supply of competitively priced animal and aquaculture products.

Performance Measure 4.1.1: Provide scientific information to maximize the production efficiency of our food animal production systems.

Baseline Performance Standard FY2012: Seven research studies on production efficiency published in peer-reviewed scientific journals that contribute evidence to improve food animal production systems.

Target Performance Standard FY2017: Cumulatively, 35 new scientific papers will be published in this area of research.

Performance Measure 4.1.2: Develop new technologies and tools contributing to improved precision animal production systems to meet current and future food animal production needs of diversified consumers, while ensuring economic and environmental sustainability and animal well-being.

Baseline Performance Standard FY2012: One new technology developed and used by ARS customers to increase production efficiency and enhance the economic value and well-being of U.S. food animal production while decreasing the environmental footprint of production systems.

Target Performance Standard FY2017: Cumulatively, five new technologies are developed and used by ARS customers.

Additional priorities relevant to NP101 can also be found in:

USDA Strategic Goal 1 Area: Nutrition, Food Safety and Quality; Goal 1.3: Enhance the economic viability and competitiveness of U.S. agriculture by maintaining the quality of harvested agricultural commodities or otherwise enhancing their marketability, meeting consumer needs, developing environmentally friendly and efficient processing concepts, and expanding domestic and global market opportunities through the

development of value-added food and nonfood technologies and products, except energy and fuels.

USDA Strategic Goal Area 2: Natural Resources and Sustainable Agricultural Systems; Goal 2.4 – effectively and safely manage and use manure and other agricultural and industrial byproducts in ways that maximize their potential benefits while protecting the environment and human and animal health. Goal 2.5 - Develop and transfer economically viable and environmentally sustainable production and conservation practices, technologies, plant materials and integrated management strategies, based on fundamental knowledge of ecological processes, that conserve and enhance the Nation's diverse natural resources found on its range, pasture, hay and turf lands; and Goal 2.6 – Develop integrated solutions to solve challenges related to agricultural system productivity, profitability, energy efficiency, and natural resource stewardship.

Research Component Overview

The NP 101 Action Plan contains general strategies and specific actions within the following organizational hierarchy: 1) Components, which are general categories of agriculturally useful research areas identified with the help of stakeholders; 2) Problem Statements, indicating the specific nature and scope of problems to be solved by ARS; 3) Research Needs, which are the kinds of research to be performed by ARS in order to achieve a successful resolution of the problem; and 4) Potential Benefits, which outline the potential benefits of the proposed research for consumers and the food production industries. The components of the program are:

Component 1: Improving Production and Production Efficiencies and Enhancing Animal Well-Being and Adaptation in Diverse Food Animal Production Systems

Problem Statement 1A: Improving the Efficiency of Growth and Nutrient Utilization

Problem Statement 1B: Reducing Reproductive Losses

Problem Statement 1C: Enhancing Animal Well-Being and Reducing Stress

Component 2: Genetic Improvement - Understanding, Improving, and Effectively Using Animal Genetic and Genomic Resources

Problem Statement 2A: Develop bioinformatic and quantitative genomic capacity and infrastructure for research in genomics and metagenomics.

Problem Statement 2B: Identify Functional Genomic Pathways and Their Interactions.

Problem Statement 2C: Preserve and Curate Food Animal Genetic Resources.

Problem Statement 2D: Develop and Implement Genome-Enabled Genetic Improvement Programs.

Problem Statement 2E: Improved Techniques For Genetic Modification and Genetic Engineering of Food Animals.

Component 3: Measuring and Enhancing Product Quality and Enhancing the Healthfulness of Meat Animal Products

Problem Statement 3A: Systems to Improve Product Quality and Reduce Variation in Meat Animal Products.

Problem Statement 3B: Improving the Healthfulness and Nutritional Value of Meat Products from Traditional and Non-Traditional Production Systems.

Component 1: Improving Production and Production Efficiencies and Enhancing Animal Well-Being and Adaptation in Diverse Food Animal Production Systems

The food animal industries in the U.S. are at a unique and critical juncture. Globally and domestically, food prices are increasing significantly and are at record levels in many parts of the world. At the same time demand for animal products is increasing as standards of living improve around the world and consumers seek the higher quality more nutrient dense foods provided by animal products. For these reasons food animal production will continue to increase, particularly across the vast areas of marginal lands around the world that are not suitable for grain or other food production. In fact, food animal production will need to be effectively doubled by 2050 to meet these demands and the demands of a growing world population.

Modern food animal production systems are growing at unprecedented rates around the world in direct competition with U.S. food animal production. Domestically, production costs have increased significantly, driven primarily by steep increases in feed grain prices, jeopardizing the historical status of the U.S. as the most efficient and least cost producer of food animal products in the world. For the food animal production systems in the U.S. to remain profitable and competitive in the face of increasing production costs, rising feed costs and increased international competition, the current levels of production and production efficiencies must continue to improve.

Historically, 50 to 60% of the total costs of producing a unit of meat or milk have been attributable to feed costs. Today, with sharply increased feed grain costs, the percentage of total costs attributable to feed is in excess of 70% in many production systems. This increase in costs has created a high priority for improvement in the efficiency of nutrient utilization and to identify strategies to mitigate feed and nutritional costs. The largest uses of feed in food animal production are the grow-finish stages for food animal production systems. Basic and applied research is needed to improve the efficiency of nutrient utilization to reduce the amount of feed required per unit of production and to increase the growth and product yield of these systems. An additional primary cost of production in the livestock industry is the maintenance of the breeding herd or flock. Two limiting factors hinder reducing this cost: 1) reproductive rate per breeding female, and 2) the relatively high energy cost required for maintenance of the breeding herd. These costs also point to the critical need to increase the efficiency of feed and forage utilization and to improve reproductive efficiencies, which are the primary drivers of production costs and of the competitiveness and profitability of the food animal industries.

Furthermore, longevity of breeding females is an important contributor to lowering costs of production. However, in several of the livestock industries the average age of breeding females has been declining in recent years, reflecting a loss of longevity. Loss of longevity and lifetime productivity is directly related to housing and environmental constraints as well as animal adaptation and well-being. All of these factors are directly related to production and production efficiencies in the food animal industries.

Successful and efficient reproduction is essential to food and fiber production from livestock and poultry. Numerous environmental factors compromise reproductive success and contribute to decreased breeding longevity. Sub-optimal embryonic, fetal, and neonatal development and survival significantly contribute to reduced reproductive efficiency in several of the food animal industries. Seasonal infertility in swine and reduced conception rates in dairy cattle breeding systems as milk yield has increased are particular areas of concern. In fact, there is a clear antagonism between production efficiency and reproductive efficiency for many food animal production systems. Improvements in milk production in dairy cattle and growth rates in livestock and poultry have occurred with simultaneous reductions in fertility even though the biological limits of these traits are considered to be significantly higher than current production levels. Very little is known regarding the biological mechanisms that influence this antagonism, but recent results from genomic analyses are now available to provide a comprehensive survey of the genes responsible for both production efficiency and reproductive efficiency which will lead to technologies to address these challenges.

Feeding and nutritional regulation of cells and organs jointly affect every aspect of livestock and poultry production. Animal industries are challenged to efficiently produce livestock products and to balance growth, feed consumption, and management of manure and nutrient by-products. Given the significantly increasing feed costs in the livestock and poultry industries, it is imperative that solutions be found to allow improved efficiency of nutrient utilization for conversion to animal and poultry products, because feed efficiency relates to virtually all aspects of economic and environmental sustainability.

Food animal production systems are considered “value-adding industries” to grain and other agricultural input commodities as well as valuable uses of land resources for vast areas considered marginal for crop production. Production systems operate in a wide range of physical and marketing environments from a highly diverse natural resource base. Proper matching of animal genotype and management system to the production-marketing environment is critical for sustainable and profitable production. This requires a comprehensive understanding of factors affecting animal adaptability and functionality, well-being, production and efficiency. The development of scientific measures of stress and well-being and an enhanced ability to interpret such measures is crucial to the evaluation of current animal agriculture management practices and development of improved alternatives. Stress caused by social, nutritional, and environmental factors and their interactions need to be understood to limit negative impacts on health, production efficiency and well-being. Society is now demanding that scientific standards for documenting animal welfare within industry production systems become a critical control point in quality assurance programs.

Problem Statement 1A: Improving the Efficiency of Growth and Nutrient Utilization

The largest costs of food animal production are feed inputs. Improving growth performance and the efficiency of nutrient utilization are primary factors for improvement of production and production efficiencies for food animal production systems.

Significant variation exists between animals in growth performance and the efficiency of nutrient utilization, characterized by measurable differences in growth rate and in the amount of feed required for a given level of production in common environments. Growth rate and feed efficiency are heritable traits, and genomic regions associated with growth rate and feed efficiency have been identified in several food animal species. Comprehensive analyses are needed to determine the genes and subsequent biological mechanisms that control the differences in growth rate and feed efficiency between animals. Suitable strategies based on the biological mechanisms responsible must be developed to predict and improve both growth performance and feed efficiency of livestock.

Food animal improvement programs continue to rapidly change genetic merit for production, particularly for rate of growth and yield of meat, milk, and eggs. Specific nutrient requirements and feeding systems must be determined and validated to allow the realization of these higher levels of genetic potential while minimizing nutrient losses to the environment. A comprehensive understanding of the metabolic or physiological functions that limit production potential is required to achieve this goal. As the genomes of food animals are annotated, opportunities are increased for using functional genomics to develop an understanding of the regulation of genes and gene complexes. This information is needed to better identify the role of specific nutrients and the physiological processes responsible for feed intake growth, feed efficiency and product yield and quality.

The symbiotic organisms that inhabit the digestive tract of food animals contribute to growth performance and the efficiency of nutrient utilization, particularly in ruminant species. Modern high throughput sequencing technologies can be used to characterize the organisms present in the digestive tract of all food animal species, and to test the value of genomic and other strategies to beneficially alter the organisms present to improve growth performance and nutrient utilization efficiency. This will allow the development of strategies to improve growth performance and feed efficiency through modifications in the gut microbe populations and demographics.

Food animals currently compete directly with the use of feed grain for bioenergy production. Programs are needed to assist producers to mitigate the use of grain for food animals by maximizing the use of forage based energy sources in ruminant species and the use of alternative feeds in all food animals. This shift in the availability of feedstuffs for food animal production, along with the concurrent increase in byproducts from biofuel production, will require attention to the development of nutritional regimens under lower energy diet systems. With implementation of low energy diet systems, possible effects on meat quality will also need to be addressed.

A substantial portion of the food animal production in the U.S. relies on forage based systems. In recent years, there has also been a growing trend toward development of pasture-based dairy and beef production systems. Effective utilization of forages by livestock suffers from a lack of adequate understanding of rumen digestion of forages in mixed diets, an incomplete understanding of the characteristics of forage plants that alter nutrient digestibility, inability to deal with toxicosis problems from some forages, and inadequate methodology for evaluating feed consumption, characteristics and digestibility.

Research Needs:

Research is needed to define the factors that predict and influence growth performance and the utilization of nutrients by food animals by delineating and elucidating the genetic and physiological systems that control or influence the efficiency of nutrient utilization. Included in these factors are genetic/genomic and basic cellular and metabolic biological systems in relationship to growth, product yield and quality and animal well-being. Through genome wide association studies, genomic regions have been identified and more will be discovered that are associated with feed efficiency. Comprehensive systems research strategies are needed to optimize feed inputs, production and production efficiencies in economically and environmentally sustainable production systems.

Research to utilize the chicken, cattle, and swine annotated genome sequences to develop an understanding of the regulation of genes and gene complexes by nutrients needs to be continued and enhanced. Developing a better understanding of metabolic syndromes in cattle through this approach is also warranted. Work to better understand feed intake in poultry and cattle should be conducted including identification of genes and gene products affecting feed intake and how they may be regulated by specific nutrients. Knowledge gaps exist in how feed efficiency may be altered in beef cattle, particularly in understanding genetic effects. Means of increasing the efficiency of nitrogen utilization are lacking and need further development in cattle and swine.

Research is needed to characterize and manipulate the metagenome of food animals to improve growth performance and the efficiency of nutrient utilization. The research infrastructure required to effectively utilize high throughput sequencing of the metagenome of livestock species must be developed, including the bioinformatics capabilities needed to store and manipulate the huge amount of data that will be generated by this endeavor. The roles of various microorganisms in feed efficiency of livestock will need to be defined. Strategies to manipulate the metagenome in various livestock species will need to be developed and their effects tested.

Research is needed to optimize forage use and characterize alternative feeds. Viable alternatives to grain are needed as an energy source, including the optimization of forage usage for nutrient needs by animals, and alternative feeds or feed components that could reduce or replace grain in livestock diets. Gaps exist in the ability to optimally utilize forages in systems for dairy and beef production including an incomplete understanding of: 1) plant characteristics and factors limiting digestibility; 2) digestive physiology; 3) transformation of

nutrients and factors affecting the partitioning of nutrients into end products from digestive fermentation; 4) animal physiological response to fescue toxicosis; 5) methodology for describing the relevant characteristics of forages including digestibility, physically effective fiber, starch, non-fiber carbohydrates; and 6) year-round forage-beef finished systems. Research is also needed to better characterize forage intake by ruminants to improve forage nutrient efficiencies.

Critical research is needed to determine the nutrient requirements of genetically-enhanced livestock and poultry in combination with genetically-enhanced feedstuffs. This includes research to address the changing composition of production diets due to the increase in the biofuels sector of the U.S. economy.

Anticipated Products:

- Elucidation of the genes and metabolic pathways that contribute to growth performance and nutrient utilization efficiency of livestock.
- Biological markers that are useful in predicting and improving growth performance and nutrient utilization efficiency of livestock.
- Strategies that alter metabolic pathways to improve growth performance and nutrient utilization efficiency in livestock.
- Best management practices and genetic selection parameters that improve the rate of improvement for growth and feed efficiency for producers.
- Comprehensive characterization of gut microflora in livestock species, including the organisms present and their prevalence, and identification of those species that are correlated with improved nutrient utilization efficiency.
- Strategies that can be used to alter gut microflora populations resulting in improved nutrient utilization efficiency in livestock species.
- Effective strategies for determination of consumption and improved use of forages to meet livestock nutrient needs
- Identification of alternative feeds that can be used to provide nutrients for livestock while maintaining production and production efficiencies and meat quality.
- Precision feeding systems for livestock and poultry that optimize nutrient availability to the animal while minimizing nutrient losses to the environment.
- Development of refined methodology allowing precise real time nutrient evaluation of forages including improved sampling procedures.
- Strategies to reduce the negative effects of fescue toxicosis in grazing livestock and realize the potential benefits of endophytes in forages.
- Development of optimized year-round forage-based finished beef systems.

Potential Benefits:

Research in this area will increase growth rates of food animals and preserve product yield and quality while reducing the use of and the costs associated with feed preserving product yield and quality and ensuring animal well-being. Research will also enable the development of precision management livestock and poultry systems that make optimal use of nutrient inputs in both intensive and extensive production environments. An understanding of gut microflora will simultaneously improve growth rate and feed efficiency of food animals. Improved understanding of the digestive environment will lead to applications to enhance cellulosic digestibility, including potential applications to other processes including bioenergy production. Similarly, an understanding of livestock nutrient metabolism and physiology will provide strategies to optimize growth rate and nutrient utilization by animals, and biological markers that can predict growth rate and feed efficiency. Optimization of forage use and the use of alternative feeds will reduce the amount of nutrients from grain needed for livestock production and their associated increasing costs. Better understanding of genetic regulation of growth rate and feed efficiency will lead to the development of nutritional modulators that increase growth performance and the efficiency of nutrient use. Improved nutrient utilization will allow optimized use of natural resources and will improve the economic and environmental sustainability of food animal industries. Development of forage-based and other less-conventional production systems opens up new value-added market opportunities for midsized and small livestock producers.

Problem Statement 1B: Reducing Reproductive Losses

Improving fertility, reproductive performance and efficiency in food animals represents the single most critical challenge to efficient food animal production and is the primary factor contributing to producer profitability and competitiveness. In addition, reducing the costs associated with maintaining breeding animals is also an important contributor to profitability. Increasing reproductive efficiencies and lifetime productivity have been a goal of food animal research for the last several decades and gains have been realized in ruminants and in non-ruminants. Gains in reproductive efficiency have occurred as a result of fertility research, most notably the widespread use of artificial insemination in many livestock species and the improvements resulting from improved nutrition throughout the life of the animal. Other gains have resulted from long term genetic selection for reproductive efficiency, for example litter size in swine. Despite these successes, there is still work to do. Fertility problems remain which contribute to inefficient production. Today, better information, emerging genetic and genomic technologies and scientific models built around large scale collaborative research promise to provide additional opportunity to improve fertility and reproductive efficiency for the food animal industries.

However, the challenges are large and complex. Reproductive capacity and reproductive longevity are lowly heritable and complex traits affected by a number of additive and non-additive genetic and physiological factors as well as significant environmental factors including temperature, humidity, photoperiod, and plane of nutrition. Managing the production environment for optimum reproductive efficiency requires an understanding of basic neuro-endocrine regulatory mechanisms, gonadal and uterine

function, development of the conceptus and interactions between the dam and the neonate. These systems may be further altered by other environmental factors including social interactions among animals, handling by humans, housing, and transportation. Prepubertal development, seasonally reduced gamete production and pregnancy maintenance, postpartum anestrous, and aging all represent periods of reproductive inefficiency in livestock and poultry. Opportunities exist to improve economic returns by determining how to combine genetic and nutritional resources in a manner that reduces the length and economic consequences of these periods of reproductive quiescence. Delays in establishing pregnancy increase cost and reduce output of food animal systems. Maximum production efficiency requires every fertilized egg to result in birth of a healthy offspring that survives and grows during the neonatal period and produces an acceptable amount of saleable product for a producer. Factors contributing to embryonic and fetal losses and/or inappropriate development in food animals are only partially understood. Incidence of embryonic and fetal mortality has been estimated to be 20 to 40% in livestock species and 10 to 14% in poultry.

An additional challenge associated with food animal fertility and reproductive efficiency is the genetic and phenotypic antagonism that generally exists between production and reproductive efficiency. Increased production of milk, growth rate, and product yield often occurs with reduced fertility. An example of this is dairy cattle, where poor fertility is a major factor interfering with production, which adds significant economic challenge to the industry. However, other food animal species demonstrate the same antagonism. In poultry for example, the reproductive capacity of broilers is much less than for layers. Studies suggest that increased leanness and growth rates in swine may have contributed to poor preweaning survival of piglets by reducing energy stores of piglets at birth. Collectively, significant improvement of reproductive efficiency will require a true "systems biology" approach to be successful including integration of all relevant genetic, physiological and environmental factors.

Finally improved reproductive efficiency reduces the number of breeding animals required for a given level of animal production, reducing the costs of maintenance of the breeding herd and improving production efficiencies. These improvements will result in increased profitability and competitiveness of producers and improve the economic and environmental sustainability of the food animal industries.

Research Needs:

Research is needed to elucidate and remediate the physiological factors that result in the antagonism between production and reproduction in food animals. Studies in numerous food animal species indicate that nutrition, metabolism, pre and postnatal growth, and previous reproductive status and lactation all effect reproductive capacity, but little is known regarding the details of the genetic, physiological, metabolic and other pathways that result in these antagonisms. Antagonistic effects of these factors on puberty, ovulation rate, embryonic, fetal and neonatal survival, and productive lifetime have all been described but problems with each still occur in various livestock species and effective strategies and remedies are needed. For example, research to address the observed decline in conception rate per service in dairy cattle is needed. Physiological and

metabolic factors underlying lowered longevity of breeding females must be elucidated to address this issue in cattle and swine.

Research is needed to address the remediation of seasonal variation in fertility and pregnancy maintenance in food animals. Many breeds of sheep and goats are obligate seasonal breeders. Improvements in utilization of these animals in production systems would be enhanced if seasonal variation could be overcome in an inexpensive cost-effective manner. Cattle and swine, despite being capable of breeding year round, also display seasonal variation in fertility. This is particularly problematic in intensive swine production and research is needed to identify the physiology underlying seasonal infertility in swine. It is currently not clear how seasonality is entrained in cattle and swine, and this must be defined before any remedial action can be undertaken.

Research is needed to develop strategies to maximize reproductive efficiency of livestock species. Even under ideal conditions, significant inefficiencies in fertility exist in all species that are not associated with level of production or seasonality. Delay or failure of puberty occurs in many animals for unknown reason. Both the male and female contribute to failure of conception. Research in the male is needed to discover the optimal production and use of semen in various species. Some loss of embryos, fetuses and neonates occurs in all livestock. Research in the female should focus on attainment of puberty; follicle development, ovulation rate, and the oocyte contribution to reproductive success; factors contributing to embryo, fetal and neonatal survival and development; and efficient return of animals to breeding readiness. While well studied in dairy cattle, factors associated with lactation efficiency in other species are not well studied.

Research is needed to elucidate the impacts of environmental stressors on successful gamete production, fertilization, and pregnancy resulting in live births for all food animal industries. Research is also needed to determine the effects of environmental factors such as air quality, housing and social interactions on reproductive function. Finally, maternal epigenetic and behavioral effects on neonatal survival should be investigated.

Anticipated Products:

- Strategies that break the antagonistic relationship between production and reproductive efficiency, allowing both to be simultaneously improved.
- Strategies to reduce seasonal effects on fertility and pregnancy maintenance of food animals.
- Strategies that optimize male and female contributions to reproductive efficiency.
- Identification of critical control points limiting improvements in reproductive rate in food animals including physiological and management factors.

- Data to facilitate appropriate matching of management and production resources with genetic potential of breeding animals with the goal of increasing reproductive rate.
- Strategies based on physiological data and biological markers for increasing longevity and lifetime productivity of breeding females in livestock systems.

Potential Benefits:
Increasing reproductive capacity, efficiency and longevity of the nation's breeding herds of food animals will lead to a more stable and profitable animal agriculture sector by ensuring reproductive success and reducing production risks and losses. Reproductive efficiency is the single most critical factor in food animal production and economic sustainability for the food animal industries. Successful research in this area will facilitate a continual incremental improvement in production efficiencies by reducing the number of breeding animals required to maintain livestock production. By spreading production costs associated with maintenance of breeding herds and flocks over more output per individual, production efficiency and profitability are concurrently increased. Optimization of management and human and natural resources with genetic potential of breeding animals has the greatest potential payoff in animal production systems in this arena. Finally, improvements in reproductive efficiency will enhance the profitability and competitiveness of the food animal industries and contribute to improved environmental sustainability and rural development.

Problem Statement 1C: Enhancing Animal Well-Being by Elucidation and Mitigation of the Adverse Effects of Stress in Animal Production Systems
Concern among the American public regarding animal well-being in food production systems continues to grow. These concerns have resulted in regulations and supply system requirements in many states governing the treatment of animals in local and regional production systems. These regulations often are not science-based, add costs to production, and in some cases decrease production capacity and efficiency. As the demand for food animal products increase, increasing production and production efficiencies will be critical to the continued viability of the U.S. livestock industries. Consequently, there is a need for research to quantify the relationship between animal well-being, production, and economic factors including: genetics/genomics, behavior, housing, health, nutrition, management, level of performance, profitability, production efficiencies, and food safety. Specific objective criteria are needed to assess animal comfort and care in typical U.S. production systems to optimize animal production cost-effectively, while ensuring animal health and well-being.

As scientifically validated measures become available, research in production environments aimed at ameliorating the potential negative effects of the production environment or management practices on well-being are needed. Development of such criteria will require an improved understanding of stress physiology and animal behavior (ethology) related to overall production efficiencies. Animal stress can originate from exposure to various natural and management stressors (e.g., environment, predators, illness/injury, social interaction, temperature/humidity, and housing systems) and

ultimately leads to production inefficiencies, compromised animal well-being, and increased animal morbidity and mortality. Heat stress alone results in annual economic losses in excess of $1.7 billion for the food animal industries in the United States. Other stressors, while not as well defined, also have substantial negative economic impacts.

In modern production systems management of stress relies on two main factors: (1) identifying the source of stress, and (2) timely management interventions to minimize or alleviate the adverse effects on individual or groups of animals. However, many stressors are difficult or impossible to detect with current production system protocols, including daily visual inspection. For example, feed/dietary changes, water quality issues, early disease symptoms (loss of appetite, pyrexia, depression) or stress associated with social interactions. Consequently, development of stress based criteria will require an integrated research approach which will include various disciplines to comprehensively understand the animal physiology and behaviors associated with various stressors in modern livestock systems. This approach will provide the information needed to make informed, science-based decisions regarding cost-effective modifications to management practices and production systems to enhance animal well-being, while ensuring economic sustainability for producers.

Definitions

The role of ARS with regard to animal well-being research is to optimize the well-being of animals in economically viable production systems while addressing animal industry priorities and supporting domestic and international food security. This concept is important because it necessitates the assumption that industry accepted production systems do actively promote economically and environmentally sustainable production; and that in general, animal well-being is optimized as evidenced by the sustainable productivity, economic viability, and competitiveness of the animal industries. Consequently, the role of ARS research is not to develop systems and practices/protocols that maximize the state of well-being of individual animals, absent the requirements of modern production systems; but rather to develop strategies and practice/protocols that optimize animal well-being in economically viable animal production systems.

The following definitions are pertinent to research programming for ARS[1]:

Animal Welfare*: describes the long term implications for an animal's well-being including both the social and scientific assessment of an animal's physical and emotional status.*

Animal Well-being*: describes the current state of the animal over a time continuum, focused on scientific assessment of quantifiable factors relating to known stressors and to the development of quantifiable measures of factors related to ethology and stress physiology.*

The following five freedoms and provisions of animal welfare have been successfully used to direct the scientific assessment of animal welfare/well-being. These tenets are generally applicable for research focused on animal well-being in ARS.

Five Freedoms and Provisions of Animal Welfare[2]:

1. *Freedom from thirst, hunger and malnutrition – by ready access to fresh water and a diet to maintain full health and vigor.*
   ARS research focus: ARS conducts research in areas related to improved production and production efficiencies including: nutritional requirements, feed consumption/efficiency, animal health and water consumption/quality. ARS animal breeding research priorities include mitigating disease and promoting optimal health and nutrition as a component of animal well-being.

2. *Freedom from discomfort – by providing a suitable environment including shelter and a comfortable resting area.*
   ARS research focus: Modern intensive production systems are organized to optimize animal performance and efficiency, minimize economic costs of production, ensure animal and worker health and safety and to adhere to regulations relevant to confined animal feeding operations. Consequently, animals in these systems are protected from extreme temperatures, provided with quality nutrition and water and managed to minimize housing and handling stressors within the confines of the production and housing systems. ARS research priorities are focused on further improving the well-being and productivity of animals in these systems through improved flooring/bedding, examination of housing systems, and improved adaptability to common stressors.

3. *Freedom from pain, injury and disease – by prevention or rapid diagnosis and treatment.*
   ARS research focus: Modern housing and management systems are designed to prevent animal disease and injury, and exposure to extreme elements. However, timely disease diagnosis is a recognized challenge for the animal industries and a priority for research. ARS research priorities include the development of "precision animal management" techniques/technologies to better predict, diagnose, and ameliorate disease or injury of individual and groups of animals in conventional production systems. Additional research priorities include quantifying pain or stress for specific production practices; prevention and/or treatment of animal disease; and a better understanding of factors relating to animal well-being such as the relationships between nutrition, health, housing, and management.

4. *Freedom to express normal behavior – by providing sufficient space, proper facilities and company of the animal's own kind.*
   ARS research focus: Modern housing and management systems are designed to provide protection from extreme temperatures, parasites and disease, and to promote optimum performance and efficiency. Modern housing systems also facilitate animal interaction and promote "normal" behaviors which serve to promote optimum performance and efficiency. However, there is no perfect system that ensures all aspects of animal welfare/well-being. For example, animals housed in outdoor production systems often are more free to express more traditional definitions of animal behavior such as rooting or foraging, but

are more susceptible to heat and cold stress, negative social interactions, disease, predation and parasites than animals housed in modern production systems. Understanding social priorities for ensuring a safe and wholesome food supply and in addressing food security, ARS research priorities include enabling animal behaviors consistent with improved animal well-being in animal production systems. These priorities are consistent with animal industry priorities to enable animal behaviors that enhance well-being while decreasing negative behaviors such as aggression.

5. *Freedom from fear and distress – by ensuring conditions which avoid mental suffering.*
   ARS research focus: This tenet is more difficult to evaluate for the animal industries. However, modern housing and management systems are designed to provide comprehensive care and management which is continually being refined to ensure optimal animal performance – which in conjunction with other quantifiable measures is an accepted measure of animal well-being. Specific management factors have been identified as potential sources of unnecessary contributors to animal fear and distress; such as euthanasia, tail docking, de-beaking and the design of some housing systems. ARS research priorities include determining the physiological responses of animals to these specific factors, and then using these stress indicators to develop novel technologies/techniques to minimize animal fear and distress in conventional production systems.

Research Needs

A more complete understanding of the physiological, immunological, microbial, and behavioral responses of all food animals to various stressors is needed to improve animal well-being and implement strategies to reduce morbidity and mortality, lessen production risk, and ensure economic sustainability. Specific research programs are needed to address industry and social priorities in animal welfare/well-being, including:

- Improved measures of animal adaptation to production environments to objectively measure response to stressors relating to animal well-being.
- Further develop and refine scientific criteria for measuring animal well-being within production systems by comprehensively utilizing endocrine and immunological biomarkers in combination with animal behavioral and production related performance data.
- Develop strategies to better identify animals that are more susceptible or resilient to production or environmental stressors - adaptation.
- Better understand animal stress and well-being in periods of extreme temperature, during transit, during transition management periods; and in concert with housing systems, genetics and genomics, structural soundness, and management practices.
- Better understand the physiology and impact of short term extreme and long term chronic stressors such as interactions with large predators in range cattle production systems.
- Develop and evaluate novel environmental management and intervention strategies, including dietary manipulations that improve animal well-being.

- Address industry priorities to accurately identify individual animals with compromised well-being in modern production systems and prescribe timely, effective interventions for known and predictable stressors such as disease, injury, loss of appetite, extreme temperatures and social interaction.
- Better understand relationships between various aspects of the immune and microbial systems, genetics and genomics, structural soundness, and animal behavior; and how these factors interact with animal well-being.
- Improved survival and well-being of neonatal animals.
- Improved animal well-being during stressful events or management practices, such as castration or the transition into lactation in dairy cattle.
- Improved mitigation of stressors relating to housing, feed characteristics, and social interaction/aggression, in animal production systems; as well as reduced indicators of negative physiological or behavior phenomenon such as aggression, gastric ulcers, lameness, injury, and disease.
- Improved mitigation of forage and secondary metabolite induced conditions, including laminitis and fescue toxicosis,
- Improved housing environments, cost-effective systems to determine gender pre-hatch, humane and cost-effective beak treatments, and improved understanding of lameness, feather pecking and aggression are needed in poultry production systems.

Anticipated Products

- Comprehensive production system best management practices that optimize production efficiencies while improving animal well-being, product quality, and economic competitiveness and sustainability.
- Objective, science-based criteria for assessment of animal stress and well-being in production systems in response to various management techniques.
- Enhanced understanding of genetic, physiological, immunological, microbial and behavioral responses of food animals to management and environmental stressors.
- Species-specific, cost-effective strategies to mitigate animal stress and improve animal well-being and longevity in conventional production systems.
- Improved precision animal management/production systems to better identify compromised animal well-being for individual and groups of animals in conventional production systems.

Potential Benefits

Research results will be used to make informed, science-based decisions regarding animal production practices and their relationship to animal stress and well-being, including:

- Strategies will be developed to cost-effectively improve animal well-being in traditional and non-traditional production systems, thus improving public perception and support of the animal industries.
- Animal stress and well-being research will benefit animals, producers, and ultimately consumers, by identifying means for reducing animal health costs and improving food animal production efficiencies.

- Achievement of these economic and societal goals will help maintain and increase demand for food animal products both domestically and internationally, particularly with regard to rapidly changing international requirements for animal well-being and production practices.
- Improved animal well-being resulting from this research will improve animal production capability and production efficiencies while improving economic sustainability for the food animal industries.

Component 2: Genetic Improvement - Understanding, Improving, and Effectively Using Animal Genetic and Genomic Resources

Understanding the relationships between the phenotype and the genotype of food animals is critical to associating their genetic makeup with production or performance for economically important traits. These associations provide effective methods to modify the traits through genetic marker assisted selection and related technologies. The process of associating differences in specific genes with differences in performance or production is termed *functional genomics,* and the goal of functional genomics is to understand the relationship between an animal's genome and its phenotype. Although significant utility of genomic associations with economically important traits can be realized without knowing the genes involved, obtaining the maximum benefit from the vast information now being generated through genome sequencing and related genomic technologies will only be possible using functional genomics techniques, which relate individual phenotypes to specific gene functions and interactions. Maximum value of research in genetics and genomics will be realized when economically important phenotypes or phenotypes relating to health and well-being for an animal are accurately predicted from its genotype.

Modern genomic techniques are applied to a wide range of traits and broad array of challenges for the food animal industries. Animal production research represents a range of meat, milk and egg production systems representing diverse environments and also a spectrum of production or management systems. These factors create extraordinary complexity, and, consequently, necessitate complex research programs to best understand and optimize the genetic value of food animal populations best suited to these production systems. Modern genetic science is challenged with addressing each of these variants in traits, production systems and environments to optimize genetic progress for the food animal industries. Consequently, comprehensive knowledge of the genome and its interactions with the environment are critical to leverage our current understanding of the biological basis of all food animal science disciplines. Because of the complexity of production traits a "systems biology" approach for research will be critical to development of improved genomic tools and technologies to increase genetic progress. Access to state of the art tools and technologies requires that USDA-ARS remain

intimately involved in the development of these critical resources. Unfettered access to these tools will result in application of economically feasible management tools for livestock producers and will spur genetic and genomic technology development for transfer to the food animal industries.

Genetic improvement of food animal populations is critical for increasing the efficient production of animal products. However, the rate of genetic improvement is hindered in many animal populations by a variety of constraints. These imitations include: a lack of phenotypic data on many economically important traits; inadequate understanding of genetic architecture underlying traits; sub-optimal methods for evaluating candidates for selection; and inefficient or non-existent strategies to incorporate genomic data into breeding programs. Tackling these challenges requires large scale phenotyping and bioinformatic efforts to facilitate the collection, management, manipulation and analysis of these data. Genome sequencing has become an essential tool to understand the connection between genotype and phenotype. Sequencing technologies are advancing at an extremely rapid pace; far outstripping existing bioinformatic infrastructure and capacity necessary to realize the ultimate goal of predicting traits from genomic data.

Finally, a wide variety of food animal breeds and unique populations around the world are at high risk because of inadequate genetic characterization. This lack of description of these resources results in a failure to recognize their value in genetic diversity. Hundreds of breeds of livestock have been lost around the world, and, on average, one additional breed is lost to extinction each month. As production systems evolve and consumer preferences or feed resources change, genetic resources that are not widely used in today's production systems may become economically important. Unique genetic variation may also be needed to respond to emerging disease threats and for environmental adaptability. These genetic resources provide producers with options that could be tailored to meet current and future demands. For these reasons, preservation of unique genetic resources is critical to the future of the food animal industries.

Problem Statement 2A: Develop bioinformatic and quantitative genomic capacity and infrastructure for research in genomics and metagenomics.

Advances in genome sequencing technologies have created tremendous opportunity in animal agriculture. Most all food animal species now have a foundational reference genome sequence or are in the process of developing a reference sequence. However, these reference sequences must continue to be improved through additional sequence information and gene annotation efforts to be used to their fullest potential impact. Sequencing technologies are now also being applied to the microbiome of the gastrointestinal tract for food animals to better understand the symbiotic, commensal and pathogenic relationships between gut microflora and food animal hosts. Technological advances now make practices such as individual genome sequencing, metagenomic sequencing, and high density genome association studies cost effective for research and,

in many cases, application. However, development and application of these and other advanced technologies are limited by the size and scope of the data sets being generated. USDA-ARS is severely limited by a lack of human capital, bioinformatic tools, resources and infrastructure necessary to manage and analyze the data.

Research Needs:

ARS research will contribute to the development of bioinformatic expertise, tools and resources to expand these capacities for research in NP101. These tools include the development and adaption of analytical tools for large data sets and data analysis pipelines to better facilitate data movement, access, curation, annotation and analysis specifically for high density panels and sequence information used in genomic and metagenomic studies. Additional bioinformatic resources and programming is needed to develop database management infrastructure and technologies and to develop and disseminate educational materials and information for bioinformatic resources. Enhanced bioinformatic resources are needed to expand the annotation of food animal genomes. Programs in extensive phenomics are needed to develop comprehensive phenotypes for novel or expensive traits and traits that are difficult to measure, but are highly relevant to important biological functions in food animals as well as programs to develop the intensive phenomics to better characterize the genetic components for traditional food animal production traits. Advanced bioinformatic tools are needed to exploit metagenomic and genomic sequence information and related genetic information for the development of improved genetic evaluation tools to increase the rate of genetic progress for economically important traits in the food animal industries.

Anticipated Products:

- Improved bioinformatic tools for data movement, access, curation, annotation and analysis of extremely large genotypic, sequence and phenotypic data sets.
- Better integration of expertise, infrastructure and genetic and genomic technologies within ARS and with industry and academic partners to facilitate development of comprehensive bioinformatic, metagenomic and phenotypic databases and tools and technologies to exploit shared resources.
- Development of comprehensive intensive and extensive phenomic and analytical tools to relate genomic and phenotypic data for development of improved genome based estimates of genetic merit including well-characterized and deeply phenotyped ARS, field and other research food animal populations.
- Improved annotation of genome sequence assemblies for food animals.

- Association of genetic and genomic effects with economically important traits.
- Enhanced metagenomic characterization and analysis of the gut microbiome to develop better understanding of the relationship between the microbiome and the health, productivity and environmental impact of food animals.
- Improved genetic evaluation and genetic selection tools and programs for industry stakeholders including integration of genetic merit into bio-economic models to optimize genetic indexing and selection programs and increase production efficiencies and economic sustainability.

Potential Benefits:

Improved bioinformatic resources and infrastructure will facilitate the management and analysis of large metagenomic and genomic sequence data sets and will provide the tools and technologies to develop large phenomic data sets for genome annotation and genome wide association studies. These tools will increase our understanding of the genes responsible for various economically important traits, providing opportunity to develop improved genetic strategies to increase genetic progress. Leveraging expertise and technologies through collaboration in and out of USDA-ARS will increase the efficiency of metagenomic and genetic and genomic research increasing the impact of USDA-ARS public research for industry stakeholders. Improved bioinformatic, metagenomic and genetic and genomic resources will facilitate the development of advanced genetic and genomic evaluation and selection technologies that will increase genetic progress for economically important traits in food animals.

Problem Statement 2B: Identify Functional Genomic Pathways and Their Interactions.

A better understanding of the functional genomics of food animals will better relate genetic expression with phenotypes for economically important traits including novel and emerging traits and traits that are difficult to measure. These relationships increase in complexity as heritability for traits decrease (i.e., complex traits such as health, disease resistance, reproduction and nutrient utilization) and as environmental influences grow, increasing the value and critical need for functional genomic studies. A better understanding of the relationship between genotype and phenotype is needed to develop genetic models to improve genetic progress in these and all traits of economic importance in the food animal industries. In addition complex traits such as reproduction and nutrient utilization are influenced by non-additive genetic effects such as dominance and epistasis, which are not well understood. Elucidation of these and all genic effects and their interactions with other traits will enable realization of the full value of research in genetics and genomics.

Research Needs:
Additional sequencing and sophisticated genome annotation along with high resolution mapping efforts are needed to associate genes responsible for variation in phenotypes. Considerable research effort in intensive phenomics is required to develop and validate the measurement of relevant phenotypes for components contributing to complex traits such as efficiency of nutrient utilization, reproductive efficiency and longevity, health, disease resistance, animal well-being and resistance to stress, product yield and quality, healthfulness and other traits. Identification of genes impacting these traits and how they interact and are regulated genetically, epigenetically, and environmentally is needed to improve genetic analysis and prediction technologies. This identification will ultimately enable the improved prediction of phenotype from genotype, significantly increasing the rate of genetic progress and improving profitability and competitiveness of the food animal industries. Finally research is needed to better understand the effect of non-additive genetic, epigenetic and environmental effects on the phenotypic expression as it relates to genotype.

Anticipated Products:

- Standardized intensive and extensive phenomic initiatives for determination of genetic and phenotypic variation for economically important traits in food animals.
- Information relating the function and regulation of individual genes and their interaction with environmental and epigenetic effects contributing to economically important traits in food animals.
- Continued improvement in the annotation of the genome sequences of food animals.
- Development of DNA-based diagnostics to provide genotypic information for use in centralized genetic evaluation and improvement systems.
- Improved genetic evaluation and genetic selection programs for the food animal industries.
- Gene targets for the development of additional strategies to beneficially manipulate the environment of the food animal to improve economic traits.

Potential Benefits:
Enhanced functional genomic research will significantly improve genetic progress in food animals through the continued development of molecularly enhanced genetic evaluations and will ultimately enable the improved prediction of phenotypes from genotypes. Functional genomics data will serve as the cornerstone for enablement of systems biology research to optimize economic and

environmental sustainability. Development of a more complete understanding of the biological systems underpinning food animal performance will ultimately lead to precision food animal selection and production management models to improve food animal health, production and production efficiencies. Ultimately, the impact of this research work will be to enhance profitability and economic competitiveness of U.S. livestock and poultry producers.

Problem Statement 2C: Preserve and Curate Food Animal Genetic Resources.
Maintenance of genetic diversity in populations of food animals is critical to the long-term competitiveness, and the economic and environmental sustainability of animal agriculture. Considering the trends of the past several decades toward increased consolidation and integration of production, along with employment of breeding systems that accumulate inbreeding within breeds and lines, this need has risen to highest priority. Furthermore, due to increased concentration of food animals, and continued increase in the easy and rapid movement of animals, the need exists to be able to respond to repopulation of animal and poultry systems in the event of a widespread disease outbreak or other catastrophe that would threaten the genetic resource base of animal agriculture. In addition, as climate change influences agriculture and food animal production, traits related to animal adaptation (i.e., heat tolerance, pest resistance, etc) may become more important, many of which may no longer exist or segregate in conventional production system populations.

Research Needs:

Germplasm collection and management requires a suite of tools to facilitate genetic analysis, cryopreservation of samples, capture of animal/sample information in a database, and potential de-accession of samples. Selection of specific germplasm to be preserved requires phenotypic and genetic characterization for a wide variety of phenotypic characteristics measured within the appropriate production environments and systems. Genetic diversity characterization of individuals within breeds and lines should be performed using a suite of tools, including quantitative approaches that utilize pedigrees, carefully designed genomic evaluations using genomic sequence information, marker systems (e.g. single nucleotide polymorphism panels), and functional genomics. This process will create a minimization of redundancy while insuring complete coverage of germplasm diversity. Considerable gaps exist in the ability to preserve gametes and embryos of the various livestock and poultry species, with the need for improved cryopreservation technologies being most critical in poultry including somatic cell technologies. The need exists to select, catalog, and curate DNA and other tissue-based collections of germplasm for both research and germplasm conservation purposes. Finally, the bioinformatics platform (Germplasm Resources Information Network, GRIN) interfacing the database of the nation's livestock and poultry genetic resources held in the National Animal

Germplasm Program should be further developed to make information quickly and readily accessible, as well as become effectively linked to other federal agencies and similar international resources. Due to the broad and vibrant nature of the livestock sector, collaboration with industry, universities and international partners will facilitate collection development and assist in quantifying the genetic diversity present in the collection.

Anticipated Products:

- A broad spectrum of genetic diversity in the form of viable and well documented livestock and poultry germplasm conserved.
- Genomic diversity in conserved populations ensured via the use of molecular technologies in selection of individuals to be preserved.
- Successful and efficient cryopreservation technologies and methods available for all livestock and poultry species.
- DNA, somatic cell and other tissue banks in place for research and genetic resource preservation purposes for livestock and poultry species.
- High-quality, comprehensive characterization, evaluation, and Genbank curatorial data made readily accessible, either from a transformed, upgraded, well-maintained GRIN, from databases housed at GRIN as the primary site, or at sites linked to GRIN.

Potential Benefits:

Careful strategic planning for and successful implementation of genetic resource management projects will provide industry users with a more dependable and more diverse source of high quality livestock and poultry genetic resources. In particular, vulnerable or threatened genetic resources will be better preserved and more secure. The National Animal Germplasm Program will be a repository of the alleles being elucidated in the post-genome sequencing era so that they may be available for long-term use by the animal agriculture industry in responding to the needs of the future. Readily available access to comprehensive and curated germplasm characterization information will allow strategic use of livestock and poultry genetic resources in fulfilling the demands for animal products in the future and to adapt to changing production priorities and criteria domestically and internationally.

Problem Statement 2D: Develop and Implement Genome-Enabled Genetic Improvement Programs.

Application of quantitative genetics theory to breed populations of livestock and poultry has resulted in significant genetic improvement in particular components of performance, primarily from the use of field data recorded in both public and private national genetic evaluation programs. Much of this improvement was facilitated by advances in statistical methodology coupled with increased scope and power of computing platforms that could be applied to large-scale pedigreed phenotypic data sets. Genetic evaluation and improvement programs have now advanced to new plateaus for the dairy industry with the development of high-density DNA marker panels and statistical methodology developed to integrate genome information with current genetic evaluation technologies. These technologies need further development for the other food animal industries. Additional technologies to genetically evaluate health traits will add significant value to the current portfolio of traits being evaluated in the dairy industry. Additionally, the focus of genetic improvement programs is now shifting to support production models that increase production efficiencies while ensuring economic and environmental sustainability on a global scale. Finally, cost effective strategies for data collection and progeny testing for optimized genetic evaluation systems would improve the value and return on investment of genetic evaluation and genomic technologies for food animal producers.

Research Needs:

The current traits included in genetic evaluation programs should be expanded to include all food animals and should include such traits as efficiency of nutrient utilization, reproductive capacity and longevity, product yield and quality, healthfulness, animal behavior, health and disease resistance and resistance to stress. This expanded set of traits will need research on a variety of parameters related to genetic evaluations that include breed effects, heterosis, heritabilities, and correlations. As new traits continue to be defined and added to the genetic evaluation pipelines, continued research on breeding objectives incorporating multiple traits under various markets is essential. Additional research is needed to increase the accuracy of the genetic evaluation estimates created for new and traditional production traits. Functional genomic research may yield diagnostics for measuring new traits. Functional genomics may also lead to tools that better define specific genes and complex genetic mechanisms including non-additive and epigenetic effects. This new molecular information must be incorporated into genetic evaluation and prediction frameworks in order to maximize genetic improvement. Additional strategies are needed to determine the most cost effective strategies to collect genotypic and phenotypic data and to optimize progeny testing in the field to optimize the value of genetic evaluation programs. Additionally, new approaches to better use comprehensive genome and haplotype

information must be investigated to improve genome selection and mating programs. The complexity of the new types of information becoming available for genetic evaluation will require significant advances in bioinformatic research and infrastructure, statistical methodology, and software to exploit these data in a commercial setting.

Anticipated Products:

- Genetic prediction tools for traits in food animals related to health, production efficiencies, adaptability, and functionality in varied domestic and international production systems.
- Improved accuracies of genetic evaluations for new and traditional production traits.
- Breeding system designs that optimize integration of genomics and traditional genetic prediction tools in domestic and international production systems.
- Demonstration of whole-genome association techniques applied to food animal industries.
- Computer software implementing statistical developments in methodology for incorporating genomic data into genetic evaluation and prediction programs, resulting in "genome-enabled" genetic improvement for the food animal industries.

Potential Benefits:

Genetic improvement programs will be enhanced by adding traits that enable producers to better match genetic potential to the production resource base and consumer and societal demands. This enhancement will lead to a more profitable and sustainable animal agriculture. Genomic-level information will allow complex traits previously excluded from genetic improvement to be evaluated, including traits essential to production system profitability. Identification and utilization of elite genetic seed stock at younger ages with higher levels of accuracy will improve the rate of genetic progress for the food animal industries. Enhanced value of public research investments in animal genomics and bioinformatics will be realized through "genome-enabled" genetic improvement programs resulting from this research. Global food security will be enhanced through adaptation of genome-aided selection methods to meet challenges of production in systems lacking infrastructure or utilizing marginal environments.

Problem Statement 2E: Improved Techniques for Genetic Modification and Genetic Engineering of Food Animals.

As the "genomic revolution" starts to deliver a tangible impact on the breeding strategies in livestock industries, the next generation of genomic tools is now being developed for application to animal production systems. Various forms of genetic engineering involving the use of genetic material to alter (improve) the livestock genome may have relevance to improving food animal production. Typically a genetically engineered organism is produced by isolating the genetic material of interest using molecular cloning methods to generate a DNA sequence containing the required genetic elements for desired expression, and is then inserted into the animal's DNA through a variety of available methods. Methods include adding a gene (transgenic), gene specific targeting and/or knocking out specific genes.

One of the most promising technologies in animal production is the development of induced pluripotent stem cells (iPSC). iPSCs will be beneficial in determining genetic effects of virtually any gene, and in elucidating metabolite pathways (e.g. for improved nutrition). "Knockout" and other related genomic technologies will help "connect the dots" between the genotype and the phenotype by demonstrating the effect of a single gene or genetic system on the basic physiology of the animal, and determining interactions with related traits (pleiotropy) and ultimately the effect on the phenotype of an organism. This technique will greatly enhance the basic understanding of the genome and will expedite research in genomics for a wide range of genetic effects.

Working in concert with modern genomic technologies and conventional animal breeding systems, iPSCs will also provide an opportunity to more rapidly advance efforts to develop genetically superior livestock for both the producers and consumers. Genetic modification offers the possibility of rationally designing beneficial gene modifications that are not necessarily found in nature. This effect will be realized by evaluating the impact of a specific allele on an animal's phenotype and then transferring the superior allele into the genome of elite breeding stock, thus facilitating the fixation of the superior allele in the genotype of the population. For example, an elite allele for growth rate or reproduction could be isolated, and then introduced and evaluated in animals of interest using iPSC site-specific gene replacement technology without changing any other genetic components in the animal's genome. If the allelic exchange was positive it could then be fixed in the population very quickly and efficiently. This practice is "hypothesis driven animal breeding" or the "ability to evaluate an isolated genetic effect in a well defined genetic background and environment" which is not possible using conventional animal breeding techniques. An additional benefit is that the allele to be tested through introduction into an iPSC derived animal could allow analyses of genes in a variety of scenarios:

- **Genes from the same species:** iPSCs could be used to systematically evaluate the various allelic effects within a breed (a single genetic lineage) of a given species, to optimize the allelic complement for any specific trait. Alternatively, a similar strategy could be employed to systematically evaluate the allelic effects from separate breeds within the same species.
- **An orthologous gene from a separate species:** iPSCs could be used to systematically evaluate an orthologous gene introduced from a separate livestock species, e.g. a goat gene in cattle.
- **An independent gene from a separate species:** iPSCs could be used to systematically evaluate an independent gene introduced from a separate species, such as a bacterial resistance gene from a microbe introduced into cattle.
- **A gene modified to improve production through rational design:** iPSCs could be used to test the effects of entirely new gene constructs on traits of interest, such as ones designed using the information gained from functional genomics studies, or studies of the physiology of feed or reproductive efficiency

iPSCs have potential application as alternatives to conventional germplasm preservation through the creation of somatic cell lines representing individual animals with specific genotypes. Somatic cell lines can be preserved indefinitely through standard tissue culture cryopreservation and once thawed could be used to create iPSCs that would then be used to regenerate an animal or genetic line.

Increasing consumer interest is also being paid to the nutritional value, safety and wholesomeness of animal products which may eventually include genetically modified animals. Information delineating the wholesomeness, quality and safety of genetically modified animal products along with ensuring the well-being of genetically modified animals will be critical to the consumer acceptance of these products.

Research Needs:

Research is needed to improve techniques to cost-effectively and efficiently generate iPSCs for food animals. Further research is needed to characterize the development of animals produced via iPSC technology and to develop the expertise and technology to implement allelic transfer and phenotypic evaluation. Research is needed to facilitate the use of iPSCs in elucidating the genetic, protein and metabolic pathways that translate the genotype (genome) to a phenotype. Research is needed to develop improved genetic modification and engineering strategies using various other related technologies. Research is also needed to develop improved technologies to develop somatic cell lines for use in domestic and international germplasm preservation programs. Finally research is needed to characterize the attributes of products derived from genetically modified meat animals.

Anticipated Products:

- Improved techniques and technologies to produce induced pluripotent cell lines for food animals.
- Programs to evaluate allelic contributions to economically important traits in food animals.
- Strategies to elucidate the genetic, protein and metabolic pathways that translate genotypes into phenotypes in food animals.
- Improved strategies to cost-effectively develop somatic cell lines for use in germplasm preservation programs.
- Scientific data for use in the decision-making process regarding the nutritional value and healthfulness of genetically modified animals in meat animal production systems.

Potential Benefits:

Genetic engineering strategies promise to increase our understanding of the genetic effects and in elucidating protein and metabolite pathways that link genotype with phenotype. Strategies to test specific allelic effects will increase the rate of genetic progress for economically important traits. Somatic cell lines will facilitate more efficient and cost effective germplasm preservation strategies. Finally, information will be available upon which to make science-based decisions regarding the utility and regulation of food animal products from genetically modified meat animals.

Component 3: Measuring and Enhancing Product Quality and Enhancing the Healthfulness of Meat Animal Products

Consumer demands are consistently evolving and meat animal producers must understand these trends and adopt production systems accordingly. Historically, the primary objective of animal agriculture was to provide income and economic sustainability in localized and integrated small farm production systems. Animal agriculture soon evolved into larger production systems focused on adding value to commodities such as grains and forages. Up until this point, little consumer influence on product quality was expressed, particularly at the farm level. As production systems grew larger and more specialized and the packing industries coalesced into larger more centralized processing centers, incentives were provided for meat animals that were uniform in type and carcass composition. Premiums and discounts were provided for animals based on a formal carcass specification criterion. However, as late as the 1980's little consumer influence was applied to meat animal production or marketing. That scenario changed dramatically when food animal products were expressly linked with

human health and specifically heart disease. Virtually overnight tremendous demand was created for meat products with a much higher percentage of lean and dramatically reduced levels of fat. The meat animal industries responded accordingly and began marketing animals with much higher percentages of carcasses lean. These changes and growing competition in the packing industries simultaneously pressured meat animal production to increase harvest weights which also increased the percentage of lean yield.

Increased body weight and lean carcass yield created many associated effects on the meat animal production industries. As meat animals grew larger and leaner, feed efficiency increased and product demand was maintained or was significantly increased (e.g., poultry). However several negative ramifications were also created. Larger, leaner market animals meant larger, later-maturing breeding stock that in many cases were compromised reproductively and created additional challenges for health, nutrition, behavior, housing, and animal well-being. Additional concerns developed regarding the eating quality of many meat products as lean percentages increased and tenderness, flavor and eating satisfaction decreased. And while much work is yet to be done, all of these issues are being dealt with by the industry through long-term basic and applied research in the areas of health, reproduction, nutrition, animal well-being and product quality. These challenges clearly illustrate the importance and influence of consumers on meat animal production.

Consumers are now adding to their demands and expectation for meat animal products in the area of nutritional value or the "healthfulness" of meat animal products. While many of the concerns regarding meat animal products such as saturated fats are not as critical as they have been in recent history, consumers are more interested in foods and meat products that promote health and vitality and limit concerns about health issues such as metabolic diseases and cancer.

In addition, a growing sector of the consuming public is demanding animal products from less intensive and non-conventional production systems including grazing dairy and beef finishing systems and natural or organic animal production systems. Product consistency and quality from these systems is relatively poorly characterized.

Today, consumers have a wide array of readily available food products, resulting in stiff competition among the sectors of the food industry. New information is continually needed to provide meat animal producers with the tools to continue to address evolving consumer preferences while preserving profitability and competitiveness for the meat animal industries.

Problem Statement 3A: Systems to Improve Product Quality and Reduce Variation in Meat Animal Products.

Product consistency and quality continues to be a major concern in the beef, swine, and small ruminant industries. Product quality issues such as flavor, tenderness, color and consistency of these attributes continue to create concerns in the meat animal production

and processing sectors due to their negative effect on consumer demand. Many of these challenges are difficult, if not impossible, to directly measure or predict on the farms making programs to improve product quality through proactive genetic selection or management impossible. Meat animal producers need better technologies to predict product quality and consistency. Processors need non-invasive, non-destructive testing procedures to identify defects and measure product yield and quality characteristics. Objective measures and systems for determining product value characteristics should allow processors to more effectively communicate value differences to producers and give producers greater incentive to improve product quality and consistency. Such "value feedback" will facilitate the development of coordinated supply chains which effectively apply all available known tools to improve product quality and consistency.

Research Needs:

Research is needed to identify technologies for measuring and predicting important traits relating to meat product quality and consistency and the biological mechanisms that control these traits. Research to elucidate the biological basis for tenderness, flavor, juiciness and other important organoleptic properties of meat is needed across all muscle cuts in meat animals, including the interaction between meat processing procedures and biochemical changes in meat postmortem. Technologies are needed to facilitate prediction of important meat quality traits including genetic and biological markers and physical data collection systems. Product variation introduced by various animal stressors has begun to be described and needs further attention. Research to develop techniques and instrumentation for the measurement and prediction of product yield and quality under commercial meat industry conditions is necessary.

Anticipated Products:

- Development of cost effective technologies to better predict and evaluate meat quality attributes on farm and during processing. Validated methodologies and instrumentation for on-line commercial industry use to determine product quality and yield.
- Identification of supply chain critical control points which can be targeted for increasing product quality.
- Better understanding of the biological mechanisms that control and influence meat product quality and consistency.

Potential Benefits:

This research will facilitate the further development of technologies to better assess and predict meat product quality and consistency. This will support development of value-based supply chains in the beef, swine, and small ruminant industries increasing profitability and competitiveness for producers. Better

understanding of the biological basis for meat quality and consistency attributes will lead to improved selection, management and processing practices which will further increase demand for meat products, lessening risk and increasing profitability for producers.

Problem Statement 3B: Improving the Healthfulness and Nutritional Value of Meat Products from Traditional and Non-Traditional Production Systems.

Consumers are becoming more cognizant of the nutritional complement and relative nutritional value of foods for human health. Meat products are no exception. Saturated fats have long been associated with increased risk of obesity, cancer, heart disease and metabolic disorders. While current research is showing that many of these associations are not accurate there is critical need to demonstrate the relative healthfulness of meat products and to develop interventions and production practices to improve the nutritional value of meat products. Increasing consumer interest is also being paid to the nutritional value of conventional and non-traditional foods including meat animals. While some research in this area has been completed, there is a lack of scientific validation and consensus regarding the nutritional value of meat animals managed under varying production system criteria. Consumers need better information concerning the quality and safety of animal products derived from these systems.

Research Needs:

Research is needed to determine target traits in meat animals and assess the amount and source of variation that exists to best develop technologies to improve the nutritional healthfulness of meat products. Strategies are needed to determine the best strategies for changing nutritional composition traits of meat products to improve their healthfulness including optimizing saturated and other fat levels and altering specific fatty acid ratios. Programs are needed to best determine the impact of changes in target traits in meat animals relating to healthfulness on human health including strategies to best utilize improved meat protein products in human diets. Additional research is needed to comprehensively characterize meat products from conventional and non-traditional meat animal production systems.

Anticipated Products:

- Improved meat products that enhance the health of consumers and promote increased demand.
- Scientific documentation of the nutritional value and healthfulness of meat products resulting from traditional and non-traditional production systems and how these profiles may be affected by environmental and management factors in the production system.

- Identification of strategies for improving nutritional composition of meat products that will result in positive impact on human health.

Potential Benefits:

Research in this area will provide foundational scientific data upon which producers can develop and implement supply chains to meet consumer demands for meat products that are more nutritionally valuable to consumers. Increased nutritive value and healthfulness will increase demand for meat products increasing the profitability and competitiveness of the meat animal industries. A better understanding of the implications for nutritive value and healthfulness for traditional and non-traditional production systems will increase production and management options for production systems of all sizes, increasing industry profitability and competitiveness.