Action Plan
National Program 101
Food Animal Production
2018-2022

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 17 national program areas through 750 projects located at 99 laboratories across the United States and abroad. The ARS national program addressing Food Animal Production involves research conducted at 13 U.S. locations by 83 full-time scientists and has an appropriated budget of approximately $48 million per annum.

Vision Statement:
The vision for National Program 101 (NP 101) entitled "Food Animal Production" is that ARS will provide the scientific community and food animal industries with scientific information, biotechnologies, and best management practices that ensure consumers an abundant supply of competitively priced, high quality animal products that enhance human health, while ensuring domestic food security, and enhancing the efficiency, competitiveness and environmental sustainability of the food animal industry.

Mission Statement:
Conduct research to improve food animal production efficiency, industry sustainability, animal welfare, product quality and nutritional value while safeguarding animal genetic resources.

Strategic Objectives:
The Food Animal Production National Program has six strategic objectives:

1) Provide science based industry relevant solutions in food-animal nutrition, reproduction, breeding and genetics, well-being, product quality and natural resource use.

2) Engage and partner with members of the food animal industries to facilitate transfer of technologies and research products to ensure that the full value and impact of research activities reaches American consumers.

3) Develop an integrated animal and microbial genomics research program that will help identify alternatives to antibiotics for enhancing production efficiency.

4) Ensure access to specialized animal genomics capacity and related technologies for all Food Animal Production research communities.

5) Foster scientific growth and individual leadership to enhance awareness of ARS scientific capabilities and accomplishments by other agencies, academia and industry stakeholders.

6) Facilitate highly effective comprehensive research collaborations between ARS laboratories, food animal industry stakeholders, academia and other federal agencies to best leverage resources and expertise for maximum industry value and impact.

Relationship to the USDA Strategic Plan

The National Program for Food Animal Production relates to the following Strategic Goals from the USDA FY2014 – 2018 Strategic Plan:

Strategic Goal 1: Assist Rural Communities to Create Prosperity so They are Self-sustaining, Repopulating, and Economically Thriving

Objective 1.2 – Increase Agricultural Opportunities by Ensuring a Robust Safety Net, Creating New Markets, and Supporting a Competitive Agricultural System. The Food Animal Production National Program will serve to protect the foundations of the agricultural system by providing leadership in creating and disseminating knowledge that reduces the costs of agricultural inputs and improves animal production efficiency. Research efforts will lead to new methods for sustaining a competitive agricultural economy and a better understanding of how to optimize use of the natural resource base. Research priorities include improving agriculturally important animals, such as those resilient to anticipated changes in climate.

Strategic Goal 3: Help America Promote Agricultural Production and Biotechnology Exports as America Works to Increase Food Security

Objective 3.1 Ensure U.S. Agricultural Resources Contribute to Enhance Global Food Security. The Food Animal Production National Program conducts basic and applied research to improve techniques and technologies, including animal biotechnologies, which assist with addressing global food security.

Relationship to the USDA Research, Education and Economics Action Plan

The National Program for Food Animal Production relates to the following Goals outlined in the REE Action Plan as revised in March 2014:

Goal 1: Sustainable Intensification of Agricultural Production

Subgoal 1A Crop and Animal Production: Research outlined in this Action Plan will serve to improve animal production and enhance animal germplasm **to safely, sustainably, and humanely** increase the production capacity, production efficiency, and nutritional value of food animals.

Subgoal1C Crop and Animal Genetics, Genomics, Genetic Resources, and Biotechnology: Research outlined in this Action Plan will enhance the sustainability of agriculture while increasing productivity by generating new fundamental knowledge through research in genomic sciences and applications to animal production. Genetic diversity will be preserved and characterized, and deployed to ensure economic and environmental sustainability and to maintain American agriculture leadership in a global, biobased economy.

Relationship to the USDA ARS Strategic Plan
The National Program for Food Animal Production relates to the 2012 – 2017 USDA ARS Strategic Plan Goal Area 4 through the following:

> ***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 1.4.1***: Provide scientific information to maximize the production efficiency of our food animal production systems. Develop new technologies and tools contributing to improve those systems to meet current and future food animal production needs of diversified consumers, while ensuring economic and environmental sustainability and animal well-being.

Relationship to ARS Grand Challenges
The National Program for Food Animal Production relates to the Grand Challenge of ***Transforming Agriculture to Deliver a 20% Increase in Quality Production at 20% Lower Environmental Impact by 2025*** by conducting research aimed at increasing production and availability of food animal products while developing sustainable approaches that reduce the environmental footprint of animal production across diverse production systems.

Introduction
Food animal production and product consumption will continue to increase globally 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 response to increasing demands for nutritious protein sources which are produced 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 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 makes the role of ARS critically important. To remain competitive in the face of extraordinary growth in animal production systems around the world, while at the same time decreasing the environmental footprint of animal production, the animal industries in the United States must continue to focus on increasing production efficiencies through the development and adoption of scientific technologies. These improvements in efficiency must be sustainable with regard to animal welfare and impacts on the environment. The application of new tools in genomics, biotechnology, metagenomics, reproductive physiology, nutrition, and molecular biology in concert with animal health and in support of traditional husbandry, animal welfare and conservation of ecosystem services will continue to

improve the long tradition of global economic competitiveness and sustainability of U.S. food animal production.

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 include increasing population, increasing demand for animal products by developing nations, rising obesity, and increasing demands for better nutrition and lower costs. Research on food animals and their production systems (management strategies, environmental impacts) is needed to meet these demands. These challenges will be met by using technologies that harness and enhance the genetic potential of animal germplasm, using strategies that are consistent with the biology of each. These technologies will be sustainable in that they cause no net harm to the animals or the environment, and will be implementable by the animal production and food marketing industries. Production systems that adopt science based strategies that harness animal biology in a sustainable way will maximize profits, secure supply, increase market competitiveness, sustain small and mid-sized producers, conserve natural resources and maintain genetic diversity and consumer confidence.

Stakeholder Engagement

In 2016 representatives of the USDA ARS National Program for Food Animal Production and the Animal Production Division of the National Institute of Food and Agriculture (NIFA) co-hosted a series of listening sessions to engage members of the academic communities, producers, allied stakeholders, and other government agencies to provide information about our collective research, education and extension programs and to solicit direction and guidance for the next 5-10 year time frame. Specifically, guidance and direction were solicited to:

- Facilitate development of USDA research, education, and extension programs to effectively address existing and emerging commodity-specific, discipline-specific, and cross-cutting issues in food animal production.

- Identify emerging food animal production issues impacting the food animal industries over the next 5-10 years.

- Explore opportunities for collaboration among ARS, NIFA, allied food animal industry and academia to maximize research capability and performance by leveraging funding, physical resources, and scientific talent.

- Develop new ideas to facilitate technology development, transfer, and implementation to industry.

Information on these sessions can be viewed at http://www.ars.usda.gov/research/programs/programs.htm?NP_CODE=101. This Action Plan identifies the valid researchable priorities from these listening sessions that ARS has the expertise and resources to address, and serves as a strategic plan to define the scope of our programs that is consistent with our Vision and Mission.

Research Component Overview

The NP 101 Food Animal Production Action Plan contains general strategies and specific actions within the following organizational hierarchy: 1) Components that are general categories of agriculturally useful research areas identified with the help of stakeholders; 2) Problem Statements that indicate the specific nature and scope of problems to be solved; 3) a Research Focus for each Problem Statement that will be addressed by ARS in order to achieve a successful resolution of the problem; 4) Anticipated Products as outcomes of research activities; and 5) Potential Benefits that describe the beneficial outcomes of the proposed research for consumers and the food production industries. The components of the program are:

Component 1: Increasing Production and Production Efficiencies while Enhancing Animal Well-Being across Diverse Food Animal Production Systems

Problem Statement 1A: Improving the Efficiency of Growth and Nutrient Utilization
Problem Statement 1B: Improving Reproductive Efficiency
Problem Statement 1C: Enhancing Animal Well-Being and Reducing Stress

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

Problem Statement 2A: Develop Bioinformatic and other Required Capacities for Research in Genomics and Metagenomics
Problem Statement 2B: Characterize Functional Genomic Pathways and their Interactions
Problem Statement 2C: Preserve, Characterize and Curate Food Animal Genetic Resources
Problem Statement 2D: Develop and Implement Genetic Improvement Programs using Genomic Tools
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: Increasing Production and Production Efficiencies while Enhancing Animal Well-Being and Adaptation across Diverse Food Animal Production Systems

The food animal industries in the United States 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 must 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 increases in feed grain prices, jeopardizing the historical status of the United States as the most efficient and least cost producer of food animal products in the world. For the food animal production systems in the United States to remain profitable and competitive in the face of increasing production costs, rising feed costs and increased international competition, and to contribute to meeting the increasing worldwide demand for animal products, the current levels of production and production efficiencies must continue to improve.

Historically, 50 to 60 percent of the total costs of producing a unit of meat or milk have been attributable to feed costs. This high percentage of the cost of production has created a high priority for improvement in the efficiency of nutrient utilization and for identification of 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. In livestock species, the limiting factors that hinder reducing this cost typically fall into the following categories: 1) reproductive rate per breeding female; 2) retention of animals in the breeding herd; and 3) the relatively high feed energy cost required for maintenance of the breeding herd. Reproductive rate includes maturation rate of animals as well as number of offspring produced. Longevity of breeding females is an important contributor to lowering costs of production because of the costs associated with developing animals for the breeding herd. Along with reproductive failure, reduced longevity is influenced by housing and environmental constraints as well as animal adaptation and well-being, which are all areas that need further research. Finally, improvements in feed efficiency of breeding animals would increase the efficiency of overall production. All of these factors are directly related to production and production efficiencies in the food animal industries.

Numerous factors reduce reproductive success and contribute to decreased breeding longevity. Sub-optimal embryonic, fetal, and neonatal development and survival significantly reduced reproductive efficiency in many food animal species. 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. Although much is known regarding these factors, which is the result of years of research by ARS and others, many questions remain unexplored and warrant further research.

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 in dairy cattle and forthcoming results in other livestock species will contribute to a comprehensive analysis of the genes responsible for both production efficiency and reproductive efficiency, which will support further development of technologies to address these challenges.

Feeding and nutritional regulation of cells and organs jointly affect every aspect of livestock and poultry production. Much more research is needed to explore the basic biological mechanisms controlling energy metabolism and growth, to inform the development of strategies to improve feed efficiency. 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 significant 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. Furthermore, improvements of production services must promote sustainability of the natural resource base.

Significant variation exists between animals in the efficiency of nutrient utilization, characterized by measurable differences in growth rate, milk and egg yield and in the amount of feed required for a given level of production in common environments. Growth rate, milk and egg yield and feed efficiency are heritable traits, and genomic regions associated with these production traits 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 these differences between animals. Suitable strategies based on the biological mechanisms responsible must be developed to predict and improve growth, milk and egg yield 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 determine production potential is required to achieve this goal. Improvements in food animal genome sequences and annotation, along with next generation sequencing capabilities, will increase opportunities for functional genomic analysis of tissues that contribute to production traits, to develop an understanding of the regulation of genes and gene complexes that affect production. As a complement to this, techniques in mass spectrometry have been developed to enable the comprehensive analysis of proteins and metabolites that contribute to nutrient utilization and growth. This basic 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. These types of experiments come with challenges in data analysis, and better methods to analyze this type of data are needed to improve the interpretation of data and the development of next steps.

The symbiotic organisms that inhabit the digestive tract of food animals contribute to growth and developmental performance, the efficiency of nutrient utilization, and health of the animal, particularly in ruminant species. Many pathogenic microorganisms compete with other organisms in these environments, and partially explain the growth promotion effects of antibiotics in food animal species. Recent changes limiting the use of antibiotics in livestock increase the importance of understanding the interactions that occur within livestock microflora, including the development of antibiotic resistance. Modern high throughput sequencing technologies can be used to characterize the organisms present in the digestive tract of all food animal species, test the value of genomic and other strategies to beneficially alter the organisms present to improve growth performance and nutrient utilization efficiency, and even to characterize the prevalence of antibiotic resistance. This will allow the development of alternative strategies to improve growth performance, milk and egg yield and feed efficiency by replacing the beneficial growth effects of antibiotics through the development of methods to make modifications in the digestive tract microbiome and/or animal metabolism.

While selection for growth efficiency and performance parameters such as lean tissue deposition and milk production are economically important, genetic selection of animals for these specific production parameters can influence immunity. Selection for growth efficiency alone can predispose animals to divert available nutrients towards production parameters, thereby diverting available nutrients towards growth parameters as opposed to the immune system. Research is needed to identify animals that are immunologically competent while simultaneously maintaining efficiency with respect to growth. Variations in animal productivity may be partially explained by variations in the ability of an animal to cope with stress and/or respond to pathogenic challenges in an efficient manner that reduces the negative impact on growth.

Certain commensal microorganisms in the gastrointestinal tract of food-producing animals and poultry are opportunistic pathogens that may initiate disease only during periods of stress or exacerbate other infections. The presence of pathogenic microorganisms in the gastrointestinal

tract, that are asymptomatic colonizers, can reduce the efficiency of nutrient utilization and negatively impact the rate of gain. Facultative pathogens in the animal production environment may increase production costs due to acute disease outbreaks and death requiring antibiotic administration. The development of alternative strategies to reduce or protect against opportunistic pathogens on the farm will decrease the use of antibiotics for disease treatment and limit production losses.

A substantial portion of the food animal production in the United States 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. A better understanding of the role and interaction of diverse forages on animal production and animal nutrient utilization efficiency is also needed. Further, a better understanding of the influences of forage type and utility on animal manure characteristics and soil health and fertility is needed, particularly for the evaluation of the fate of carbon and nitrogen in integrated dairy and animal production systems. For example, nitrogen is necessary for efficient nutrient utilization and production of meat and milk, but contributes directly to environmental issues such as nitrate leaching and ammonia volatilization. Consequently, improving nitrogen use efficiencies in animal systems is needed and has direct implications for forage crop and animal production system capacity and efficiency as well as environmental sustainability of food animal systems.

Research Focus

Research is needed to define the factors that predict and influence growth and developmental performance and the utilization of nutrients by food animals. Included in these factors are genetic/genomic and basic cellular and metabolic biological systems that influence growth and development, product yield, quality and healthfulness, animal well-being, and the generation of manure and emissions from animal production systems. Comprehensive systems research strategies are needed to optimize feed inputs and production efficiencies in diverse economically and environmentally sustainable production systems.

Research is needed to improve the chicken, cattle, and swine genome sequences, including understanding of genetic diversity within and between breed and comprehensive and accurate annotation contributed by subject matter experts. Once these are in place, research is needed in functional genomics to increase our understanding of the genes that influence traits and how they function. Complementary analyses of proteins and metabolites are needed to enhance our understanding of nutrient utilization processes, and to develop biomarkers that could be used as indicators of high and low efficiency livestock, and to improve the environmental sustainability of integrated animal production systems. 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. Knowledge gaps exist in how feed efficiency may be altered in

dairy and 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, to provide tools to reduce the environmental impact of livestock. Bioinformatics capacity to manage and analyze these data sets must be expanded and implemented.

Research is needed to characterize and manipulate the microbiome of food animals to improve growth and developmental performance and the efficiency of nutrient utilization; to reduce emissions of methane and other greenhouse gases; as an avenue for mitigation of the loss of antibiotics for growth promotion, and as an avenue to further assess the contribution of livestock to antibiotic resistance. Continued development of the research infrastructure required to effectively utilize high throughput sequencing of the metagenome of livestock species is needed, including the bioinformatics capabilities needed to store and manipulate the huge amount of data that will be generated by this endeavor. Research is needed to develop interventions to decrease opportunistic pathogens in the gastrointestinal tract that reduce the rate of gain and predispose animals and poultry to infectious diseases. Management tools are needed to protect animals and poultry against facultative pathogens that require antibiotic administration to control acute disease outbreaks. Alternative strategies to antibiotic administration need to be developed for suppression of opportunistic pathogens in order to limit production losses and curtail the development of antimicrobial resistance. 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 for dairy and beef cattle and small ruminant production systems. 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; including the role of the rumen and gut microbiome on forage and nutrient use efficiency, animal performance and animal/manure emissions; 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 nutrient utilization efficiencies, as well as improve rangeland health and sustainability and conserve ecosystem services.

Research is needed to determine how non-antibiotic supplements can provide immunological protection without diverting nutrients away from economically important production parameters. To accomplish this research, a better understanding of how changes in metabolism modulate immune function in livestock is required.

Anticipated Products

1) Elucidation of the genes and metabolic pathways that contribute to growth and developmental performance and nutrient utilization efficiency of livestock.
2) Biological markers that are useful in predicting and improving growth performance and nutrient utilization efficiency of livestock.
3) Strategies that alter metabolic pathways to improve growth performance and nutrient utilization efficiency in livestock.
4) Best management practices and genetic selection parameters that improve the rate of improvement for growth and feed efficiency for producers.
5) Comprehensive characterization of digestive system microflora in livestock species, including the organisms present and their prevalence, and identification of those species that are correlated with improved performance, nutrient utilization efficiency, and reduced environmental impact.
6) Strategies that can be used to alter digestive system microflora populations resulting in improved nutrient utilization efficiency in livestock species.
7) Effective strategies for determination of consumption and improved use of forages to meet livestock nutrient needs.
8) Identification of alternative feeds that can be used to provide nutrients for livestock while maintaining production and production efficiencies and meat quality.
9) Precision feeding systems for livestock and poultry that optimize nutrient availability to the animal while minimizing nutrient losses to the environment.
10) Development of refined methodology allowing precise real time nutrient evaluation of forages including improved sampling procedures.
11) Strategies to reduce the negative effects of fescue toxicosis in grazing livestock and realize the potential benefits of endophytes in forages.
12) Development of optimized year-round forage-based beef finishing systems, including the use of crop residues, cover crops and summer/fall annuals.
13) Identification of alternatives to antibiotics for improving growth performance in livestock.
14) Management strategies and programs for improving grazing-land health and sustainability and conservation/return of natural ecosystem services.
15) Reducing stress and the severity of disease through the use of pre-, pro- and para-probiotics.
16) Identification and development of alternatives to antibiotics to decrease pathogens and improve growth performance in livestock and poultry.

Potential Benefits

Research in this area will improve the development and growth rates of food animals and preserve product yield and quality, ensure animal well-being, and improve economic and environmental sustainability.

Research will allow optimal use of nutrient inputs in both intensive and extensive production environments. An understanding of the digestive system microbiome will simultaneously improve productivity, growth rate and feed efficiency of food animals, and may contribute to the replacement of the use of antibiotics for growth promotion and feed efficiency. 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, product yield and nutrient utilization by animals, and identify 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 and other concentrated feed sources needed for livestock production and their associated costs, lessen the use of food suitable for human consumption, and improve global production efficiencies. 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 potentially creates novel value-added market opportunities for midsized and small livestock producers.

Problem Statement 1B: Improving Reproductive Efficiency

Improving reproductive performance and efficiency in food animals represents the single most critical challenge to efficient food animal production and is a primary factor contributing to producer profitability and competitiveness. In addition, reducing the costs associated with developing and maintaining breeding animals is also an important contributor to profitability. Increasing reproductive efficiency has been a goal of food animal research for several decades and gains have been realized. A notable example is the widespread use of artificial insemination in many livestock species and the improvements in fertility 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, further improvement in reproductive efficiency is needed. Fertility inefficiencies remain that contribute to inefficient production. Today, better information, emerging genetic, genomic, proteomic and metabolomic technologies and scientific models 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 low heritability 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 and others that are still unclear. Managing the production environment for optimum reproductive efficiency requires an understanding of basic neuro-endocrine regulatory mechanisms, gonadal and uterine function, and conceptus-dam interactions throughout gestation and into the neonatal period. These systems are likely to be influenced by environmental factors including social interactions among animals, handling by humans, housing, and transportation. Prepubertal development, seasonally reduced gamete production, pregnancy maintenance, postpartum anestrous, and aging all represent periods of reproductive inefficiency in livestock and poultry. Opportunities exist to improve economic returns by developing strategies that mitigate inefficiencies that result from problems within each of these reproductive categories. 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 percent in livestock species and 10 to 14 percent 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 and increased 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 development and maintenance of animals in 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 Focus

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 affect 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. Functional genomic analyses including transcriptomic, proteomic and metabolomic analyses of various reproductive tissues are needed to provide a comprehensive analysis of factors that affect fertility. Similar to their use for analysis of growth and feed efficiency, data analysis challenges will occur and research is needed to enhance the generation of knowledge from these types of experiments.

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 reasons. 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, and are needed to enhance the survival, growth and development of neonatal animals.

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

1) Strategies that break the antagonistic relationship between production and reproductive efficiency, allowing both to be simultaneously improved.
2) Strategies to reduce seasonal effects on fertility and pregnancy maintenance of food animals.
3) Strategies that optimize male and female contributions to reproductive efficiency.
4) Identification of critical control points limiting improvements in reproductive rate in food animals including physiological and management factors.
5) Data to facilitate appropriate matching of management and production resources with genetic potential of breeding animals with the goal of increasing reproductive rate.
6) Strategies based on physiological data and biological markers for increasing longevity and lifetime productivity of breeding females in livestock systems.
7) Strategies based on the concept of fetal programming to improve prenatal development and subsequent reproductive performance of replacement females.
8) Complete characterization of the mechanism of implantation in cattle to mitigate embryonic losses.

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 and Reducing Stress

Concern among the American public regarding animal well-being in food production systems continues to grow. Some members of the private sector have embraced more stringent criteria for animal well-being, which have translated to marketing of their products to consumers. Furthermore, public concerns have resulted in regulations and supply system requirements in many states governing the treatment of animals in local and regional production systems. These and future regulations and production criteria should be science-based in terms of their effect on animal well-being, because they often add costs to production, and in some cases decrease production capacity and efficiency. There is also the public perception that increased production efficiency takes a toll on the well-being of the animal. However, 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. Techniques must be developed that increase efficiency without detrimental effects on the welfare of livestock. For these reasons, there is a need for research to quantify the relationship between animal well-being, production, and economic factors including: genetics, 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 with respect to cost-effectiveness, while ensuring adequate animal health and well-being.

As scientifically validated measures become available, research in production environments aimed at ameliorating possible 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. Feed/dietary changes, water quality issues, early disease symptoms (loss of appetite, pyrexia, depression) or stress associated with social interactions are all examples. Consequently, development of criteria that indicate that animals are not adequately coping with stress will require an integrated research approach to understand the animal physiology and behaviors associated with various stressors in modern livestock systems. Further, stress reduces production efficiency by diverting energy and nutrients, obtained through intake of feed and energy stores in the body, towards survival mechanisms and away from growth. Also, stress has been associated with subclinical disease and the redistribution of energy and nutrients to the immune system, which further reduces performance. This ultimately increases time on feed, treatment costs and overall production costs through loss of production efficiency associated with stress and immune interactions. Valid indicators of stress in food animals 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.

The role of ARS with regard to animal well-being research is to safeguard the well-being of animals in economically viable production systems while addressing animal industry priorities and supporting domestic and international food security. 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 practices/protocols that ensure animal well-being while improving the economic viability of animal production systems.

The following Five Freedoms of animal welfare (Farm Animal Welfare Council: http://webarchive.nationalarchives.gov.uk/20121007104210/http:/www.fawc.org.uk/freedoms.htm) have been successfully used to direct the scientific assessment of animal welfare/well-being. These tenets are applicable for research focused on animal well-being in ARS.

Five Freedoms of Animal Welfare

1. *Freedom from thirst, hunger and malnutrition – by ready access to fresh water and a diet to maintain full health and vigor.*
   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.*
   Modern intensive production systems are organized to optimize animal performance and efficiency, minimize economic costs of production, and 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.*
   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 and 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.*
   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 and 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.*
   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 Focus

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 and 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 such as lactation; as they interact with predators, during disease, as a consequence of social interactions, and in concert with housing systems, genetics and genomics, structural soundness, and management practices (e.g. castration).
- Develop and evaluate novel environmental management and other intervention strategies, including dietary manipulations that improve animal well-being.
- Improved survival and well-being of neonatal animals.
- 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.
- Better understanding of the interaction between stress, immune function and metabolism, including how uncharacterized or unidentified subclinical disease may alter metabolic profiles and divert energy availability away from growth and towards immunity.

Anticipated Products

1) Comprehensive production system best management practices that improve production efficiencies while also maintaining or improving animal well-being, product quality, and economic competitiveness and sustainability.

2) Objective, science-based criteria for assessment of animal stress and well-being in production systems in response to various management techniques.
3) Enhanced understanding of genetic, physiological, immunological, microbial and behavioral responses of food animals to management and environmental stressors.
4) Species-specific, cost-effective strategies to mitigate animal stress and improve animal well-being and longevity in conventional production systems.
5) Improved precision animal management/production systems to better identify compromised animal well-being for individual and groups of animals in conventional production systems.
6) Development of specific management strategies (e.g., time of animal processing and vaccination, use of non-antibiotic supplements, etc.) targeted at reducing animal stress and improving immunity.

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 Resources

The following ARS locations have research projects addressing Problem Statements identified under Component 1:

- Ames, Iowa
- Beltsville, Maryland
- Clay Center, Nebraska
- Dubois, Idaho
- El Reno, Oklahoma
- Lexington, Kentucky
- Lubbock, Texas
- Madison, Wisconsin
- Miles City, Montana
- Mississippi State, Mississippi
- Stoneville, Mississippi

- West Lafayette, Indiana

Component 2: 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. 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 when we understand the role of genes and gene polymorphism on the traits of interest. Maximum value of research in genetics and genomics will be realized when economically important phenotypes are accurately predicted from individual animal genotypes, and we understand the function of the gene with respect to the trait of interest.

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 that take place in diverse environments and 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 determining the effects of DNA variants in the diverse 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 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 limitations 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. In addition, problems and inconsistencies with the current livestock genomes create difficulties in understanding the role of specific genes in traits of interest, and a significant effort is required to resolve these problems through new sequencing and annotation efforts. Tackling these challenges requires large scale phenotyping and bioinformatic efforts to facilitate the collection,

management, manipulation and analysis of these data. Further genome improvement is needed to facilitate an understanding of the connection between genotype and phenotype.

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 other Required Capacities for Research in Genomics and Metagenomics

Advances in genome sequencing technologies have created tremendous opportunity in animal agriculture. Most food animal species now have a foundational reference genome sequence. However, these reference sequences must continue to be improved through additional sequence information inclusive of broad genetic diversity 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. High-throughput proteomics and metabolomics have also vastly increased our ability to generate phenotypes for genomic association. These technologies are also very data intensive, and bioinformatics research is required to obtain the full value of these new tools. ARS is severely limited by a lack of human capital, bioinformatics tools, resources and infrastructure necessary to manage and analyze these types of data.

Research Focus

ARS research will contribute to the development of bioinformatic expertise, tools and resources to expand these capacities for research in NP 101. These tools include the development and adaption of analytical tools for large data sets and data analysis. We will also improve data pipelines to better facilitate data movement, access, curation, annotation, and analysis. Improvements are needed specifically for data arising from high density panels and sequence information used in genomic and metagenomic studies. Additional bioinformatic resources and programming are needed to develop database management infrastructure and technologies. Finally, to increase utility of these resources, we will develop and disseminate educational materials and information for these 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 proteomic, metabolomic, 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

1) Improved bioinformatic tools for data movement, access, curation, annotation and analysis of extremely large genotypic, sequence and phenotypic data sets.
2) 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 tools, and technologies to exploit shared resources.
3) 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.
4) Improved annotation of genome sequence assemblies for food animals, including participation in the Functional Annotation of Animal Genomes consortium.
5) Association of genetic and genomic effects with economically important traits, including but not limited to growth, feed efficiency, reproductive efficiency, and production efficiency.
6) 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.
7) Improved tissue/body fluid based phenotypes based on broad spectrum protein and metabolite analysis.

Potential Benefits

Improved bioinformatic resources and infrastructure will facilitate the management and analysis of large proteomic, metabolomic, metagenomic, and genomic sequence data sets and will provide the tools and technologies to develop large phenotypic 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 ARS will increase the efficiency of metagenomic and genetic and genomic research increasing the impact of 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: Characterize 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. Transcriptomic, proteomic and metabolomic efforts will help inform the connections between the genotype and phenotype of an animal. Elucidation of these and all genetic effects and their interactions with other traits will enable realization of the full value of research in genetics and genomics.

Research Focus

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 establish the connection between genotype and 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, contribute to our understanding of how phenotypes are generated from the genotype, significantly increase the rate of genetic progress and improve 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

1) Standardized intensive and extensive phenomic initiatives for determination of genetic and phenotypic variation for economically important traits in food animals.
2) 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.
3) Continued improvement in the annotation of the genome sequences of food animals.
4) 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, Characterize 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 Focus

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. The need exists to select, catalog, and curate DNA and other tissue-based collections of germplasm for both research and germplasm conservation purposes. 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

1) A broad spectrum of genetic diversity in the form of viable and well documented livestock and poultry germplasm conserved.
2) A publicly available database providing germplasm sample, phenotypic, and genomic information to industry and the research community.
3) Genomic diversity in conserved populations, germplasm and tissue are ensured via the use of molecular technologies in selection of individuals to be preserved.
4) Successful and efficient cryopreservation technologies and methods available for all livestock and poultry species.
5) DNA, somatic cell and other tissues available for use in various research projects and which can be used as a reference resource for genomic studies such as gene editing.
6) High-quality, comprehensive characterization, evaluation, and Genbank curatorial data will be readily accessible.

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 Genetic Improvement Programs using Genomic Tools

Application of quantitative genetics theory to breed populations of livestock and poultry has resulted in significant genetic improvement, in particular components of performance. This has been accomplished 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 Focus

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. In addition, biological traits that are correlated with production traits will be developed that allow for improved selection of complex traits. This expanded set of traits will need research on a variety of parameters related to genetic evaluations that include breed effects, heterosis, heritabilities, and genetic 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

1) Genetic prediction tools for traits in food animals related to health, production efficiencies, adaptability, and functionality in varied domestic and international production systems.
2) Development of DNA-based diagnostics to provide genotypic information for use in centralized genetic evaluation and improvement systems particularly for novel traits.
3) Improved genetic evaluation and genetic selection programs for the food animal industries.
4) Improved accuracies of genetic evaluations for new and traditional production traits.
5) Breeding system designs that optimize integration of genomics and traditional genetic prediction tools in domestic and international production systems.
6) Demonstration of whole-genome prediction techniques applied to food animal industries.
7) 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.

8) Elucidating environment and genetic interaction effect on growth performance in livestock.

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. Historically, 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.

It has now become possible to make very directed and specific changes in genes of animal cells through the use of Transcription Activator-Like Effector Nucleases (TALENs) and Clustered Regularly Interspaced Short Palindromic Repeats (CRISPR) technologies. Using these technologies, specific modifications to genes can be made that are essentially indistinguishable from the natural polymorphisms that occur in nature. If this is done with stem cells, or in fact with any animal cells, nuclear transfer technologies allow the generation of livestock with the directed DNA change. Thus, if one knows or suspects that a particular DNA modification is the cause of a particular phenotype, it has now become possible to make that DNA modification without making any other nonspecific changes in the genome. An example of this is the polled gene transferred into dairy cattle, this modification has occurred without altering the rest of the genome. Thus, 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 elite animals of interest. 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. Despite current regulatory uncertainties, research is needed to explore and advance the huge potential of this technology for improvement of animal performance and well-being. Some of the strategies are listed below.

- Genes from the same species: Gene editing 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: Gene editing 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: Gene editing 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: Gene editing 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.

Increasing consumer interest is also being paid to the nutritional value, safety and wholesomeness of animal products which may eventually include genetically modified animals. Many of the modifications to be made will be natural mutations found in other populations. However, as the technology matures, more extensive and more sophisticated modifications will be used to improve livestock species. Information will be needed 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 Focus

Research is needed to develop improved genetic modification and engineering strategies using site specific technologies (TALENs, CRISPR, etc.) including research to support regulatory agencies in the decision making process. Research is needed to characterize the attributes of products derived from genetically modified meat animals.

Anticipated Products

1) Programs to evaluate specific DNA modification techniques (i.e., Gene editing) to determine the effects of natural mutations and rationally designed modifications on economically important traits in food animals.
2) Strategies to elucidate the genetic, protein and metabolic pathways that translate genotypes into phenotypes in food animals to inform gene modification design.

3) Scientific data for use in the decision-making process regarding the nutritional value, healthfulness and animal well-being impact of genetically modified animals in meat animal production systems.

Potential Benefits
Genetic engineering strategies promise to increase our understanding of genetic effects that link genotype with phenotype. Strategies to test specific allelic effects will increase the rate of genetic progress for economically important traits. 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 Resources
The following ARS locations have research projects addressing Problem Statements identified under Component 2:

- Athens, Georgia
- Beltsville, Maryland
- Clay Center, Nebraska
- Dubois, Idaho
- El Reno, Oklahoma
- Fort Collins, Colorado
- Miles City, Montana

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 correlated changes also occurred. Larger, leaner market animals meant larger, later-maturing breeding stock that in many cases had altered reproductive and other characteristics, creating 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. These changes are ongoing and require research to delineate both their scope and remediation. 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 Focus

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

1) 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.
2) Identification of supply chain critical control points which can be targeted for increasing product quality.
3) Better understanding of the biological mechanisms that control and influence meat product quality, color stability 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 some of these associations may not be accurate there is a 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 Focus

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

1) Improved meat products that enhance the health of consumers and promote increased demand.
2) 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.
3) 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.

Component Resources

The following ARS locations have research projects addressing Problem Statements identified under Component 3:

- Clay Center, Nebraska
- Dubois, Idaho
- El Reno, Oklahoma