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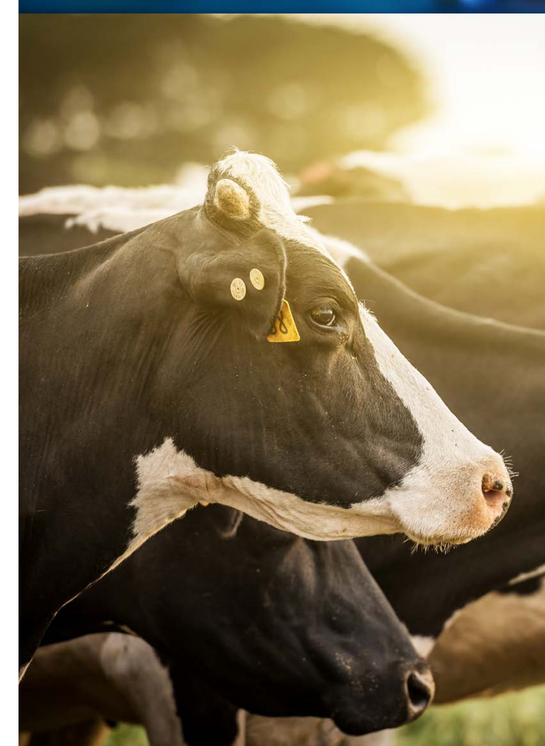
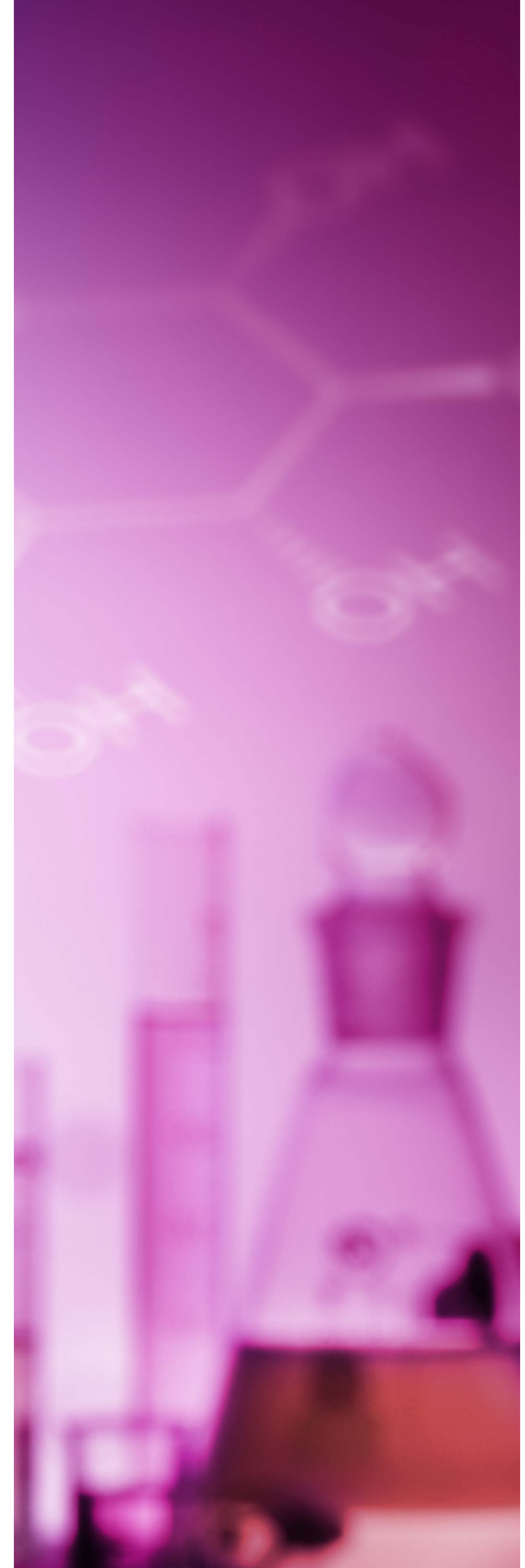


USDA AGRICULTURE INNOVATION AGENDA

U.S. AGRICULTURE INNOVATION STRATEGY: A DIRECTIONAL VISION FOR RESEARCH

January 2021



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INTRODUCTORY MESSAGE

Agriculture in the United States has a long history of leading the world in using innovative approaches and technologies. Based in sound science, agricultural innovation has improved both the production and the production capability of the Nation to feed a growing population sustainably. Indeed, over just the past 90 years, U.S. agricultural output has increased by 400 percent with no aggregate increase in required inputs and with 10 percent less land required for that result. But, while there has been no net increase in inputs, the form and function of the inputs used has certainly changed, with hundreds of innovations contributing to productivity gains.

These innovations have allowed producers to be more productive, more profitable, and more resilient in adapting to changing environmental and economic conditions. Moreover, the innovations have enabled farmers, foresters, and ranchers who have always been stewards of their land to be even more conservation minded with innovative practices and technology employed for soil health, waste cycling, and environmental protection.

The impact to the Nation of agricultural innovation is felt far beyond the farmgate. For consumers, the result has been a reliably safe, abundant, and affordable food supply. U.S. citizens enjoy a rich array of nutritious foods and on average spend only about 10 percent of their disposable income on food (Source: USDA, Economic Research Service, Food Expenditure Series).

As we recognize progress, however, we must also focus on the horizon. The journey to produce enough food, feed, fuel, and fiber to meet the demands of a growing population while protecting the natural resource base on which agriculture depends, for both current and future production, is never complete. For this reason, USDA Secretary Sonny Perdue announced in February 2020 the **Agriculture Innovation Agenda (AIA)**, with a goal of increasing U.S. agricultural production by 40 percent, while cutting the environmental footprint of U.S. agriculture in half by 2050. This is a compelling goal and of such magnitude that we must think differently, meaning we must seek to develop new and truly transformative innovations for agriculture. One component of the AIA is the formulation of a **U.S. Agriculture Innovation Strategy** – seeking to establish discovery goals that align with or inform both the public and private-sector research ecosystems.

This document and the detailed information available in other documents and online tools represent the first version of the **U.S. Agriculture Innovation Strategy** and is formulated from a public Request for Information (RFI) whereby USDA sought to solicit the "voice of the customer." The RFI asked all stakeholders to propose the biggest opportunities and challenges that should be addressed over the next 10 to 30 years to achieve the overarching goals of the **Agriculture Innovation Agenda**. The response was voluminous, with a wide range of agricultural groups, consumer groups, science groups, nongovernment organizations, and individual citizens offering their perspectives, insights, and recommendations. USDA worked to ensure all viewpoints and perspectives were considered and incorporated in the strategy. Yet, like innovation itself, development of a contemporary strategy for agriculture is an iterative process, so we expect continuous additions and refinements over time as additional inputs are received. This is a synopsis of the directional feedback provided. We recognize this summary does not include all agricultural segments. However, this is a starting point for moving the innovation community forward in reaching agricultural research goals and Agriculture Innovation Agenda outcomes. We urge the agricultural community to engage with USDA in the future. These data should be used to inform next generation agricultural solutions with producers, end users, and consumers in mind.

The United States is well equipped for the challenges outlined in this strategy, in large part due to the extensive investments and talent focused on agricultural research at USDA and within universities, especially the extensive Land-Grant University System, which was created with the foresight to ensure the continued growth of agriculture through modern innovations.

The research, teaching, and extension mission of these great institutions, along with USDA Science Agencies, has always been the "edge" that keeps U.S. agriculture a global leader, and this strategy outlines aspirational goals worthy of continued investment and focus. But, every bit as important as public-sector research is private-sector innovation.

We intend for the goals outlined to inform the broad research innovation ecosystem in the United States and worldwide. The strategy requires public-private partnerships to achieve success, and the goals are outlined over multiple time horizons to galvanize and focus all sectors on common outcomes.

Agriculture is a noble profession, not just for the farmers, foresters, and ranchers who practice it, but also for those who enable it with their scientific endeavors, their innovative ideas and applications, and their commitment to genuine partnerships for progress toward sustainably feeding our growing world. USDA is pleased to provide this U.S. Agriculture Innovation Research Strategy as a key element of the USDA Agriculture Innovation Agenda to help fulfill the mantra of "***Do Right and Feed Everyone.***"

Scott H. Hutchins, Ph.D.
Deputy Under Secretary for Research, Eduction, and Economics
United States Department of Agriculture

John M. Dyer, Ph.D.
U.S. Ag Innovation Strategy Coordinator
United States Department of Agriculture

BACKGROUND

Innovation has always been at the heart of American agriculture. From new cultivars that produce more nutritious foods and other critical agricultural products to management practices that enhance and protect the production capabilities of our farmers, foresters, and ranchers, innovation in agriculture clearly benefits all of humanity.

The U.S. agriculture sector has shown remarkable growth over the past 90 years, with a 400-percent increase in production of food and fiber (Figure 1). This has taken place over a time when input amounts have remained relatively flat. Increases in agricultural production were instead driven mainly through development and incorporation of new innovative approaches, tools, and technologies. Despite these great successes, there are challenges ahead to meet increased food, feed, fuel, fiber, and enviornmental demands.

TECHNOLOGICAL INNOVATIONS

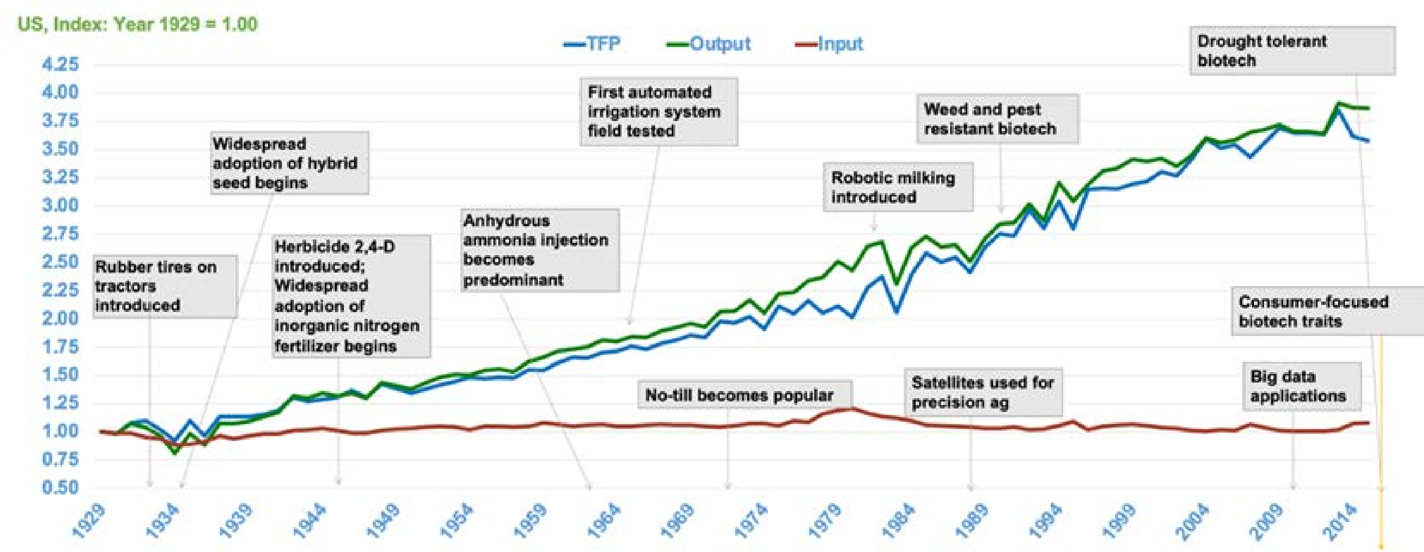

Figure 1. Total factor productivity (TFP) of U.S. agriculture over time. Shown are major technological innovations and their approximate date of development and adoption. The red line represents total aggregate inputs; the green line represents total aggregate outputs; the blue line represents total factor productivity, which is the ratio of outputs over inputs.
Source: USDA, Office of the Chief Economist using data from USDA, Economic Research Service and historic USDA data (pre-1948).

To meet these future challenges, USDA set ambitious goals to further increase agricultural production by 40 percent, while cutting the environmental footprint of U.S. agriculture in half by 2050. To achieve these goals, USDA launched a bold new initiative in February 2020 called the **Agriculture Innovation Agenda (AIA)**, which represents a Department-wide effort to align USDA's resources, programs, and research to provide farmers with the tools they need and to position American agriculture as a leader in the effort to sustainably meet future food, fiber, fuel, and feed demands.

The AIA is comprised of three interdependent workstreams and a single coordinated scorecard. The Research Workstream is focused on developing a U.S. Agriculture Innovation Strategy that aligns and synchronizes public- and private-sector research to target innovative solutions needed over the next 10 to 30 years to solve the AIA challenges and goals.

The Programs Workstream aims to align the work of USDA customer-facing agencies and integrate innovative technologies and practices into USDA programs to help fast-track their adoption by producers. The Metrics Workstream seeks to analyze USDA productivity and conservation data to develop benchmarks in six areas, enabling USDA to evaluate its progress and maintain accountability. These six areas comprise the scorecard, which includes agriculture productivity, forest management, food loss and waste, carbon sequestration and greenhouse gas, water quality, and renewable energy.

DEVELOPMENT OF THE U.S. AGRICULTURE INNOVATION STRATEGY FOR RESEARCH

The Agriculture Innovation Strategy is conceptually broken down into three parts. In the first, USDA leveraged a 2019 report from the National Academy of Sciences entitled "Science Breakthroughs to Advance Food and Agricultural Research by 2030" to derive four innovation clusters where advances in science were predicted to have a major impact on increasing agricultural productivity and reducing environmental footprint in the future. These innovation clusters include Genome Design, Digital and Automation, Prescriptive Intervention, and Systems Based Farm Management (see Box 1 for characterizations). A fifth area identified in the National Academies' report, which focused on the microbiome, is considered largely inclusive within the Genome Design innovation cluster.

The second stage of building the Agriculture Innovation Strategy focused on collecting the "voice of the customer"—the end-users of technologies including farmers, foresters, and ranchers. Inputs were collected through two mechanisms, including publishing a Request for Information (RFI) in the Federal Register, and encouraging stakeholder groups to hold workshops or listening sessions (Appendix 1). The goals of the RFI and workshops were similar – identify perspectives on the major opportunity areas in support of the Agriculture Innovation Agenda goals and develop high-priority aspirational goal statements that create a vision for outcome-oriented solutions, or discovery goals, to be developed in each of the four innovation cluster areas to support those aspirational goals.

The third part of the Agriculture Innovation Strategy aims to formulate the discovery goals to focus public sector research opportunities and inform private sector product goals to align these processes to target innovative solutions for the future.

GENOME DESIGN

Using genomics and precision breeding to explore, control, and improve traits of agriculturally important organisms.

DIGITAL AND AUTOMATION

Deploying precise, accurate, and field-based sensors to collect information in real time to visualize changing conditions and respond automatically with interventions that reduce risk of losses and maximize productivity.

PRESCRIPTIVE INTERVENTION

Applying and integrating data sciences, software tools, and systems models to enable advanced analytics for managing the food and agricultural system.

SYSTEMS-BASED FARM MANAGEMENT

Leveraging a systems approach to understand the nature of interactions among different elements of the food and agricultural system to increase overall efficiency, resilience, and sustainability of farm enterprises.

DATA COLLECTION, ANALYSIS, AND SYNTHESIS

A total of 223 responses were collected through the RFI from across the agricultural value chain, including responses from farmers, private citizens, researchers, private companies, and stakeholder groups (Appendix 2). USDA manually assessed the data to identify emergent themes and common aspirational goal statements that stakeholders shared across multiple RFI responses. The RFI provided sufficient data for developing discovery goals for four major agricultural segments including crops (inclusive of row and specialty), forestry, beef and range, and dairy. Unfortunately, there was insufficient input from other agricultural areas submitted during this initial call for inputs. Additions and refinements of goals should be further developed in subsequent versions of this report or directly with stakeholders to expand to other agricultural topic areas. Nonetheless, many of the discovery goals have multiple-use utility and can support a wide range of production systems. In addition, as progress is made and new learning and discoveries occur, there will always be room for refinement and adjustment to better align on the metrics and outcomes of the Agriculture Innovation Agenda.

THREE MAJOR TOPIC AREAS AND ASSOCIATED ASPIRATIONAL GOAL STATEMENTS WERE IDENTIFIED:

PRODUCTION

Increase agricultural production by optimizing yield and/or quality with higher input use efficiency and crop resiliency

PRODUCTION CAPABILITY

Increase agricultural production capabilities of soil, water, and air by developing and implementing sustainable farming and forestry tools and practices

MARKET EXPANSION AND DIVERSITY

Increase market diversity and product utility of the agricultural system to expand value, reach, and resiliency

Each aspirational goal statement is supported by outcome-oriented discovery goals in each of the four innovation cluster areas. The discovery goals are presented over an "Innovation Horizon" including "Incremental Solutions to Accelerate," "Transformational Solutions to Create" (we can see it, but achieving it will be a heavy lift), and "Next Era Concepts" (we can imagine it, but we do not yet clearly envision the path to get there). Also included is a description of the "Gaps, Barriers, and Hurdles" that describe research and regulatory or other types of hurdles that need to be addressed (per the respondents) to enable discovery goal solutions.

For brevity, this written report includes a short summary of the discovery goals in each area. For a complete description of all discovery goals and "Gaps, Barriers and Policies," please visit the dashboard related to this report (www.usda.gov/AIS-dashboard). The dashboard provides an intuitive interactive interface for exploring the data by various topic areas and allows for generating customized reports that focus on areas of interest (e.g., genome design solutions for crops; digital and automated solutions across all topic areas, etc.). It is intended to be a living product that connects discovery goal areas to ongoing areas of intramural and extramural research, funding opportunities, cutting-edge areas of science, and linkages to public/private efforts. The goal is to help people and companies engage with the U.S. Agriculture Innovation Strategy by enabling data exploration based on areas of interest, and rapid identification of people, programs, and funding to stimulate engagement.

VIEWING FUTURE INNOVATIONS THROUGH THE SUSTAINABILITY LENS

The major joint goals of the USDA Agriculture Innovation Agenda are to increase agricultural production by 40 percent, while reducing the environmental footprint of U.S. agriculture in half by 2050.

These bold goals are needed to stimulate transformational innovations for a step change in the trajectory of U.S. agricultural productivity (Figure 1) necessary to meet the demands for safe, nutritious food, feed, fuel, and fiber for a growing population, while also stabilizing and enhancing the environmental services required to support agricultural activities. Woven throughout these major goals are the long-standing principles of sustainability that underpin and guide all USDA activities.

Three essential facets of sustainability help guide the development and consideration of future innovations in U.S. agriculture. The first is economic sustainability. Future tools and practices should generate additional on-farm income or have significant return on investment. At the heart of it, farming is a business, and adopting and implementing new innovations and practices should have clear economic benefits for farmers, foresters, and ranchers.

The second facet is environmental sustainability. Producing safe, nutritious food takes place within the environment, and innovative tools and practices should stabilize and/or improve the quality of soil, water, and air to help increase the agroecosystem production capability. Farming is part of the environmental solution, and innovative tools and practices should not only help build resiliency into the farming system, but also help mitigate the effects of a changing climate. Farmers, foresters, and ranchers are important stewards of the land and have long been recognized for the environmental services that they provide.

The last facet is social sustainability. Food and agricultural systems that do not result in abundant, nutritious, and affordable food, fiber, feed, or fuel or the delivery of ecosystem services are not fulfilling their social purpose.

EMERGENT THEMES ACROSS MULTIPLE AGRICULTURAL SEGMENTS

The RFI respondents provided a wealth of compelling examples of bold opportunities and innovations to support the AIA goal, demonstrating that innovation within and across the four innovation clusters can make a significant impact.

Theme: Genome Design

There is universal interest in developing crops, trees, and animals that have higher production capacity, stress resilience, pest and disease resistance, and higher nutrient use efficiencies. Enabling these solutions requires new platforms and processes that greatly accelerate the breeding pipeline, including advances in predictive genomics that identify desired genetic changes delivering specific phenotypic outcomes. End-use traits should offer clear economic, environmental, and societal benefits. The microbiomes of soil, crops and animals offer untapped potential for further increasing agricultural system productivity. Farmers, foresters, ranchers, and the general public need educational resources on the benefits of genome design and consumer acceptance, and their input is essential for product development, adoption, and implementation.

Policies (such as Executive Order 13874) and regulatory frameworks are needed that provide clear guidance on development, adoption, and deployment of genome design solutions, and international policies need harmonization to ensure acceptance in both domestic and international import/export markets.

Theme: Digital and Automation

Low-cost, easy-to-use, broadly dispersed sensors and biosensors are needed across all agricultural sectors, providing real time information with high spatial resolution in areas of active cultivation. Standards are needed for data collection, processing, and management to enable device designs that function seamlessly in the Internet of Things. Broadband access to rural communities is needed to underpin the digital agricultural environment, including wireless networks with access to cloud-based computing. Digital tools and solutions should be scale-neutral, and useful for all types of farming/forestry systems and environments. Digital tools should also collect data that quantify environmental benefits to validate conservation programs and enable ecosystem service markets and carbon sequestration markets. Automated solutions are needed that deliver precise input amounts with high temporal and spatial resolution, and/or address common issues in the agricultural production system, including worker availability and improvements in worker safety. Automated data collection and reporting processes could enhance existing survey methods and create a data-rich environment (with protections) for further enabling the digital agricultural environment. Blockchain or similar types of technology, coupled with sensors that detect product quality and safety, are needed to ensure transparency, traceability, and safety throughout the agricultural production system.

Theme: Prescriptive Interventions

Decision support tools are universally needed that integrate real-time, geopositioned data with predictive algorithms to make recommendations that improve production or reduce environmental impacts. Data fusion and analytics currently represent major bottlenecks to the conversion of enormous amounts of raw data into useful information. Standards are needed to enable design of interoperable tools that can be organized into an enterprise system, rather than the current array of options that require independent learning and support systems.

Theme: Systems-Based Farm and Forest Management

Systems tools should be easy to use and establish linkages between broad agricultural sectors and markets, enabling design of farming and forestry systems that maximize economic, environmental, and social benefits. Tools should also enable adjustments in the farming/forestry system to minimize risks and maximize productivity during changing market or environmental conditions, integrating very complex information into a simple and intuitive interface. Developing and establishing robust systems tools and models will require truly transdisciplinary interactions between disparate scientific groups, as well as public/private partnerships, and high-quality data are needed to develop and train models and systems. Systems tools should also consider regional and cultural differences, as well as product distribution systems that might be altered by global challenges or pandemics. Public engagement should drive systems design, thereby connecting on-farm activities with end-user demand. Shortened supply chains offer increased potential for enhancing farmgate value by connecting people more directly to the source of nutritious food and products.

ENERGIZING AND ENABLING THE AGRICULTURAL INNOVATION ECOSYSTEM

The next era of farming and forestry tools and practices offers numerous potential benefits, but ensuring their adoption requires a better understanding of the factors influencing decisions to develop proper incentives and risk mitigation approaches. Education, training, and technical support is also needed in support of adoption and implementation, and methods are needed for quantifying impacts of new tools and practices. A technically sound workforce is needed to support next-gen agricultural innovations, including multidisciplinary training in areas such as biology, ecology, economics, systems thinking, and data science. The university cooperative extension system plays a key role in supporting tech transfer to end users and delivery of next generation tools, practices, and students needed for a successful agricultural environment. Public-private partnerships are needed to identify shared goals, identify priority areas for research and development, develop standards for data collection and usage, and develop opportunities to engage the broader innovation community including nontraditional agricultural partners.

USDA agencies have been very effective in supporting the needs of specific stakeholders and customers, but new linkages are needed across USDA to enable and support a broader innovation ecosystem that leverages and integrates expertise in research, education, economics, conservation practices, and forestry. A comprehensive plan and vision need to be developed and supported at all levels, with senior leadership committed to long-term goals and objectives. Regular communication, collaboration, and partnerships between innovation ecosystem players help ensure development of shared goals, identify new and emerging targets and opportunities, and ensure accountability to the future success of American agriculture in the delivery of a safe, secure, abundant, and nutritious food supply.

DISCOVERY GOALS TARGETING FUTURE INNOVATIONS IN U.S. AGRICULTURE

The discovery goals described below, summarized from the RFI, provide a roadmap for achieving this broader vision, but aligned to specific agricultural segments. Each section includes an aspirational goal statement and a short summary of the discovery goals identified by stakeholders who offered input to the RFI in each of the four innovation cluster areas (Genome Design, Digital and Automation, Prescriptive Intervention, and Systems Based Farm Management). For a complete description of discovery goals and gaps, barriers, and hurdles, visit the online dashboard (www.usda.gov/AIS-dashboard).

Crops: Production

Aspirational Goal: Increase agricultural production by optimizing yield and/or quality with higher input use efficiency.

Innovative tools and practices will enable production of more crops, with less inputs, on the same amount of land. Advances in crop genetics aim to dramatically increase carbon fixation and nutrient use efficiencies, while maximizing crop production traits, nutrition, and resistance to biotic and abiotic stresses. An enhanced microbiome fixes nitrogen and increases nutrient availability, health, and resiliency of all crops. Digital tools comprehensively scout and map a field for yield limiting parameters, and prescriptive interventions enable targeted delivery of precise amounts of inputs at the individual plant level. For specialty crops, tools that allow staging of harvest with market demand, along with extensive automation of the harvesting process itself, will transform the timeliness of harvesting with much greater labor efficiency and reduced food loss and waste. Systems analysis tools integrate data from across the farm, allowing farmers to collect, analyze, and use data from their own fields to manage crop production precisely and profitably.

Crops: Production Capability

Aspirational Goal: Increase agricultural production capabilities of soil, water, and air by developing and implementing sustainable farming tools and practices.

Crop varieties have improved below ground traits, including larger roots that fix more carbon and enhance soil health. Deep-rooted perennial varieties are developed for all major row crops. An expanded portfolio of value-added cover crops and crop rotation practices offer numerous choices for improving soil health and environmental benefits. Digital sensors monitor soil health indicators and provide quantitative data that support conservation programs, Ecosystem Service Markets, and Carbon Credit Markets. Field drainage systems recycle nutrients and water on the farm, and soil amendments and novel microbiomes further increase soil health, carbon content, and greenhouse gas reduction. Agroforestry practices such as windbreaks, shelterbelts, and stream restoration are common, offering numerous environmental benefits including clean air, enhanced water quality and quantity, and improved wildlife habitat and biodiversity, including pollinators. Whole-farm modeling uses high-quality, farm-scale data to enable selection of a diverse array of crops and management practices that maximize environmental and economic benefits and allows farmers to significantly alter their farm system based on actual or expected changes in climate.

Crops: Market Expansion and Diversity

Aspirational goal: Increase market diversity and product utility of the farming system to expand value, reach, and resiliency.

Strong market pull enhances and energizes the farm system, with crop varieties developed for diversified end uses such as organic, biofuels, bioproducts, consumer quality traits, and optimal animal feeds. Crops are tailored for regional production environments and support diversified and shortened supply chains. Digital tools and sensors enable traceability and product safety, from farm to fork, allowing full transparency and connection with end-user demand. Automated solutions address common labor choke points, and areas along the food production chain are identified where rapid changes can be implemented to re-route or re-distribute food when market accessibility changes. Comprehensive farm modeling systems integrate data from across the agricultural production chain and include social and regional considerations that allow for selection of diverse crops, animals, and management practices that maximize economic, environmental, and societal benefits.

Forestry: Production

Aspirational Goal: Increase forest production and forest ecosystem health by optimizing yield and/or quality with higher input use efficiency and resistance breeding.

Our Nation's forests provide multiple environmental benefits and uses, and genome design solutions include germplasm resistant to insects, diseases and abiotic factors for all tree species of commercial or ecological value, including urban forests. Satellites, drones, and ground-based sensors are integrated to provide higher resolution, diagnostic, spatially explicit data informing forest health issues including insects, diseases, plant diversity, and abiotic stressors. Decision support tools evaluate forest health indicators and recommend rapid interventions that maximize environmental and economic benefits. Systems-based analysis enables development of best management practices for forest plantations, such as using mixed species and intensive forestry management, leading to healthier forests that produce larger volumes of fiber and carbon, offer better protection of water quality and wildlife habitat, and avoid catastrophic wildfires.

Forestry: Production Capability

Aspirational Goal: Increase forest production and ecosystem health capabilities to benefit human health and soil, water, and air by developing and implementing sustainable forestry management tools and practices.

Forests deliver a multitude of environmental services, and genome design enables the development of integrated packages of new tree varieties, or mixtures of tree species, combined with organisms of the phytobiome. Together they enable more robust growth, deeper roots (that fix more carbon in the soil) and improve soil health indicators. Standards and digital tools are developed at appropriate scales for management and measuring carbon sequestration and flux and other ecosystem services such as air quality, water quality, and healthy soils. Decision support tools integrate above-ground (e.g., topologic, climatologic, biophysical, biological, and land use), ground-level (e.g., soil type and soil moisture), and below-ground (e.g., microbial composition, diversity, and root-related processes) data with data analytics and artificial intelligence to uncover and monitor soil health and ecosystem variables to optimize forest production capability and expand ecologically diverse forests. Agroforestry practices are expanded in agricultural production regions, increasing environmental benefits and agricultural production capability. Comprehensive forest modeling systems recommend best management practices that increase carbon sequestration, water quality protection, and other ecosystem services that are measured and quantified, enabling Ecosystem Service Markets and Carbon Sequestration Markets.

Forestry: Market Expansion and Diversity

Aspirational goal: Increase market diversity and product utility of the forestry system to expand value, reach, and resiliency.

Robust, diverse marketing opportunities for wood-based products drive forest production and management systems that increase carbon storage, increase environmental and societal benefits, and maximize economic returns including jobs and (STEM) science, technology, engineering, and mathematics education opportunities. Genome design solutions include trees with high-value end-use traits tailored for use in building materials, biofuels, bioproducts, etc., and enzymes and microorganisms are identified that enhance production efficiencies of biofuels and/or bioproducts from forest-related residues. Digital tools and sensors enable identification, detection, and treatment of pests associated with trade, or in nurseries, before they impact forest systems. Financial assessment models enable development of economically viable forest restoration programs in fire prone ecosystems. Systems analysis tools consider and recommend various value-added marketing opportunities such as diversified wood products (e.g., lumber, building materials, biochar, cellulosic nanomaterials) or feedstocks for bioenergy and recommend best management practices for their delivery.

Beef and Range: Production

Aspirational Goal: Increase agricultural production by optimizing yield and/or quality with higher input use efficiency.

Innovations in genome design enable a 10-fold increase in the rate of genetic gain, delivering healthier animals that require fewer calories with low mortality and high growth rates. Strong immune systems reduce the need for antibiotics, and animals have high resistance to infections and diseases and produce low amounts of enteric methane emissions. A customized rumen microbiome contributes to high nutrient use efficiency, improves animal health, and further reduces enteric methane emissions. Low-cost, easy-to-use diagnostic sensors and biosensors provide real-time, animal-specific data that inform animal health, stress levels, and the presence of pathogens or disease. Sensors also monitor forage crop production and quality and are coupled to automated solutions such as virtual fencing to optimize animal nutrient intake and range/pasture utilization. Feed formulations maximize nutrient use efficiencies and leverage microbiome activities, and prescriptive livestock farming enables individual-animal-targeted nutrition, health, and welfare. Animal facilities and environments are designed to minimize animal stress and maximize well-being and productivity, and systems-analysis tools consider marketing, nutrition, herd health, weather, and other on-farm activities to recommend reliable, sustainable, intensified animal production systems that have a positive impact on the environment, support animal welfare, and optimize profitability while mitigating risk.

Beef and Range: Production Capability

Aspirational Goal: Increase agricultural production capabilities of soil, water, and air by developing and implementing sustainable farming tools and practices.

The coupling of forage, feed, and animal production systems offers numerous environmental and economic benefits. Livestock production efficiencies are increased through development of forage and feed crops with improved production efficiencies, thereby leveraging genetic enhancements developed for crop production systems.

Forages with improved nutrient content and digestibility for animals are used as cover crops, and perennial grass stands serve as forages that increase soil carbon content. Sensors monitor forage quality and yield, and tools are developed to measure rangeland health indicators such as carbon sequestration, water quality, air quality and GHG emissions, biodiversity, biotic integrity, soil/site stability, and hydrological function. Sensors and decision support systems scout the rangeland to detect invasive annual grasses such as cheatgrass (with limited forage value) and other pests, and recommend a suite of prescriptive interventions and management practices to mitigate these pests, improve wildlife habitat, increase livestock production, and reduce risk and extent of wildfires across the range. Advanced grazing management is used to reduce forage loads and improve rangeland health, for instance, by coupling virtual fence controls with sensors that inform forage quality and quantity. Systems-based farm management considers economic and environmental benefits across the agricultural production chain including production of animal forage and feed, herd health, advanced grazing management, rangeland management, agroforestry, manure management, and marketing to recommend best practices that improve livestock health and production with increases in environmental, economic, and societal benefits.

Beef and Range: Market Expansion and Diversity

Aspirational Goal: Increase market diversity and product utility of the farming system to expand value, reach, and resiliency.

Development of cattle that are more resistant to heat leads to increased production of beef in impacted regions and expanding into new geographic areas. Cattle are developed for specific regions of the country and tailored to key sections of the beef production chain. Blockchain or similar technology enables traceability through the food production system, connecting food production with end-user demand. Sensors detect and diagnose the presence of pathogens and diseases, including zoonotic diseases, across the supply chain, and are integrated with a global surveillance system that detects emerging biological threats, tracks their global movements, and anticipates mitigation strategies to minimize losses and increase public safety and economic prosperity. Automated solutions address common chokepoints and improve worker safety. Areas along the food production chain are identified where rapid changes and interventions can be implemented to re-route or re-distribute food when market accessibility changes. New and value-added uses for animal waste are developed that generate additional on-farm revenue and reduce environmental footprint, and systems-analysis tools enable design and optimization of diversified farming systems that include both animal and cropping systems to maximize economic, environmental, and societal benefits while reducing risk.

Dairy: Production

Aspirational Goal: Increase agricultural production by optimizing yield and/or quality with higher input use efficiency.

Dairy production is increased by improving overall animal health and performance. Additional genome design solutions target increased milk production, for instance, by increasing fertility and longevity to reduce the ratio of non-productive to productive years or bringing cows to milk without birthing a calf to reduce over-breeding of calves and extend cow longevity.

Sensors and biosensors monitor animal health and welfare, enabling prescriptive livestock farming that enables individual-animal-targeted nutrition, health, and treatment. Decision support tools enable daily monitoring of milk and activity data for each cow, coupled with advances in detection for signs of stress or disease and recommended interventions that reduce the negative impact of removing a cow from the milking string for treatment. Systems-analysis tools consider marketing, nutrition, herd health, weather and other on-farm activities and recommend reliable, sustainable, intensified animal production systems that have a positive impact on the environment, support animal welfare, and optimize profitability while mitigating risk.

Dairy: Production Capability

Aspirational Goal: Increase agricultural production capabilities of soil, water, and air by developing and implementing sustainable farming tools and practices.

The environmental footprint of dairy production is reduced by developing forage or feed crops with improved resource use efficiency, disease and stress resistance, and improved nutritional content and digestibility. Cover crops are planted in rotation with feed crops to improve soil health, increase yields, increase drought and pest resistance, reduce herbicide use, increase water retention, reduce the need for tillage and increase the potential for soil carbon sequestration. An enhanced soil microbiome increases nutrient availability for feed and forage crops, while the animal microbiome reduces deamination of feed proteins and increases digestion of phytic acid, thereby maximizing nutrient use efficiencies and reducing nitrogen and phosphorus contamination from manure. Broadly distributed, low-cost, biodegradable sensors and biosensors quantify and inform crop and soil health indicators with high temporal and spatial resolution, and decision support tools recommend a suite of amendments, biostimulants or other products to improve soil health and stability (e.g., on-farm manure use). Additional sensors monitor forage quality and yield, enabling prescriptive interventions that maximize crop yield and manage the timing of harvesting or grazing. Systems-based whole farm modeling considers interactions between different elements of a dairy operation to drive improvements in milk production, reduce enteric emissions, optimize feed production and manure and nutrient management.

One hundred percent perennial dairy production systems are available that achieve net-zero nutrient loss and carbon emissions and provide sufficiently nutritional forages for modern milk production levels.

Dairy: Market Expansion and Diversity

Aspirational goal: Increase market diversity and product utility of the farming system to expand value, reach, and resiliency.

Milk characteristics are defined that contribute to human health to enable breeding of animals that deliver designer milks for improved human health outcomes. Dairy cows more resistant to heat lead to geographic expansion of milk production, and microbes are identified that increase yields of methane generation from anaerobic digesters. Automated measures including more reliable milking systems, combined with decision support tools, help farmers increase production and reduce labor. Blockchain or similar technologies enable traceability from farm to fork, and sensors detect the presence of pathogens and diseases, including zoonotic diseases, across the supply chain. Diversified opportunities exist for using manure as a feedstock for value-added products such as fertilizers or energy production, generating on- and off-farm economic and environmental benefits. Systems-based whole farm predictive tools assess tradeoffs of management interventions on productivity and environmental impacts and recommend prescriptive management interventions that improve the economic and environmental performance of dairy farms.

Data

Aspirational Goal: Standardize, align, and integrate agricultural research and operational data to enable and energize a broad informatics ecosystem to drive tomorrow's agricultural operations and State and Federal programs.

Data standards are developed that enable the collection, management, and extensibility of high-throughput sequencing, phenotyping, genotyping, and field-based studies to populate centralized and/or interlinked databases to enable deep data analytics and digital design of crops and animals. Standards define what needs to be measured on the farm or forest stands/plantations, and when, where, and how to report the data (e.g., information on cropping systems, soil health indicators, nutrient/water status, conservation practices, farmer demographics, production metrics, etc.). Automated data collection processes enhance existing survey methods, enabling a data rich environment and seamless interactions between USDA and end-user communities. Standardized, interoperable data and protocols are available for third parties to develop decision support tools or other digital agricultural solutions that maximize data value and usage. Systems analysis tools identify deep linkages between disparate datasets, enabling the modeling and design of optimized agricultural systems that maximize economic, environmental, and societal benefits.

NEXT STEPS IN THE RESEARCH JOURNEY

Achieving the broader goals of increasing agricultural production by 40 percent while decreasing the environmental footprint by half by 2050 will require bold steps forward by all members of the agricultural production value chain. This document provides a vision for future research priorities in the public and private sector based on outcome-oriented solutions desired by the agriculture and forestry community. It is essential that all segments of the agricultural community work together to address these goals; they will not be solved by any one entity, and alignment of the public and private-sector innovators is essential for progress.

While this document presents a high-level overview and vision, the online version of this report allows for a deeper dive into the data as well as important learning about the gaps, barriers, and hurdles that need to be addressed. The Web interface also allows for cutting and sorting the data to generate customized reports that focus only on topic(s) of specific interest. A future iteration of this website intends to link various discovery goal areas to ongoing research efforts across the Department and funding opportunities. The goal is to create a process that invites all to join the agriculture innovation ecosystem by first identifying topics of interest, then informing on the people, players, and funding available for engagement.

The discovery goals described here represent a current vision for the future, but there will no doubt be changes and adjustments as new information is collected, new challenges arise, and new discoveries are made. Future iterations will include additional discovery goals for agricultural areas that are not yet represented. This is intended to be an "evergreen" process that requires future evaluations and adjustments to maintain alignment with a sense of accountability.

Appendix 1. Stakeholders Engaged

American Farm Bureau Federation
American Forest and Paper Association
American Soybean Association
American Seed Trade Association
American Sugarbeet Growers Association
Beet Sugar Development Foundation
California Aquaculture Association
Corn Refiners Association
Dairy Farmers of America
Florida and Texas Sugarcane Growers
Indiana Corn Marketing Council
Indiana Soybean Alliance
International Dairy Foods Association
National Association of Wheat Growers
National Association of State Foresters
National Aquaculture Association
National Cattlemen's Beef Association
National Chicken Council
National Corn Growers Association
National Cotton Council
National Farmers Union
National Grain and Feed Association
National Milk Producers Federation
National Pork Producers Council
National Turkey Federation
Potato Sustainability Alliance
United Fresh Produce Association
U.S. Endowment for Forestry and Communities
U.S. Farmers and Ranchers Alliance
USA Rice
Western Growers

Appendix 2. Stakeholders that Provided Written Input

Accenture Federal Services
Ag Alumni Seed
AGree Economic and Environmental Risk Coalition
Agribusiness Council of Indiana
Agricultural and Applied Economics Association
Agricultural Industry Electronics Foundation
AgriNovus Indiana
American Farm Bureau Federation
American Farmland Trust
American Floral Endowment
American Forage and Grassland Council
American Phytopathological Society
American Seed Trade Association
American Society for Microbiology
American Society for Nutrition
American Soybean Association
Anuvia Plant Nutrients
Apache County, Arizona
Association of Public Land-Grant Universities
Arkansas Forestry Association
Association of Equipment Manufacturers
Association of Northeast Extension Directors
Barenbrug USA
BASF
Beck's Superior Hybrids
Biotechnology Innovation Organization (BIO)
Bipartisan Policy Center
Cargill
Carolina Farm Stewardship Association
Center for Invasive Species Protection
Center for Science in Public Interest
Chesapeake Bay Foundation
Colorado Dept Natural Resources and Department of Agriculture
Corn Refiners Association
Cornell University Cornell Alliance for Science
Corteva Agriscience
Cotton Incorporated
CropLife America
Dairy Management Inc
Deep Sea Fisherman's Union of the Pacific
Defenders of Wildlife and others
Ecosystem Services Market Consortium
Elanco
Entomological Society of America
Farm Foundation
Farm Journal Foundation
FASS Science Policy Committee
Fertilizer Institute
Field to Market
Food and Agriculture Dialog
Foundation for Agronomic Research
Fresh and Processed Pear Committee
Genesis Systems
Good Food Institute
Growth Energy
Grand Farm Initiative
Gund Institute for Environment at University of Vermont
Harvest Select
Humane Society
HyFrontier

Illinois Hemp Growers Association
Indiana Ag Nutrient Alliance
Indiana Corn Marketing Council
Indiana Dairy Producers
Indiana Soybean Alliance
Indiana State Department of Agriculture
Indiana State Poultry Association
Indigo
Innovation Center for U.S. Dairy
Iowa Corn Growers Association
Izaak Walton League of America
John Deere
Kansas Forage and Grassland Council
KWS Seeds LLC
Metrostar Systems
Michael Fields Agricultural Institute
Microsoft
Mom and Pop Products Co.
National Agricultural Aviation Association
National Alfalfa and Forage Alliance
National Alliance of Forest Owners
National Association of State Foresters
National Association of Wheat Growers
National Biodiesel Board
National Cattlemen's Beef Association
National Corn Growers Association
National Cotton Council
National Cotton Ginners' Association
National Council of Farmer Cooperatives
National Farmers Union
National Grain and Feed Association
National Grazing Lands Coalition
National Milk Producers Federation
National Sustainable Agriculture Coalition
National Wildlife Federation and 10 others
Natural Resources Defense Council
Nevada Board of Commissioners
New York Farm Viability Institute
Newtrient LLC
Novozymes
OpenTEAM (Open Technology Ecosystem for Agricultural Management)
Oregon Trawl Commission
Organic Farming Research Foundation
Pivot Bio
Plant Based Products Council
Produce Marketing Association
Purdue University Research Leadership Team
Renewable Fuels Association
Sand County Foundation
Scientific Societies Combined Responses (American Society of Agricultural and Biological Engineers, American Society of Agronomy, American Society of Plant Biologists, Crop Science Society of America, Entomological Society of America, National Association of Plant Breeders, International Certified Crop Advisers, and Soil Science Society of America)
Saratoga-Encampment-Rawlins Conservation District – Wyoming
Supporters of Agricultural Research (SoAR)
Texas A&M Agrilife
Texas Cotton Ginners' Association
The App Association
The Nature Conservancy
The Organic Center
The Seam
Trust in Food
Union of Concerned Scientists
University Coastal Experiment Stations
University of Tennessee Commission on Agriculture
UPL Ltd
US Beet Sugar Industry
US Ignite
USA Rice
Western Extension Directors Association
Western Integrated Pest Management Center
Western Landowners Alliance