U.S. Agriculture Innovation Strategy
General Ag Area: Full Report

CROPS - PRODUCTION

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

Genome Design

Incremental Solutions To Accelerate

- Crops selected for improved input-use efficiency traits, yield/quality traits, or stress resiliency.
- CRISPR-generated (Clustered Regularly Interspaced Short Palindromic Repeats) elite lines containing single- or several-gene traits with producer and/or end-user benefits.
- Cotton varieties selected for increased fiber yield or improved fiber quality traits.
- Cotton varieties selected for increased input-use efficiency or stress-resiliency traits that maintain or increase fiber quantity or quality.

Transformational Solutions To Create

- Crops with a 20-percent increase in CO_2 fixation, nutrient use efficiency, and/or water use efficiency.
- Crops with high tolerance to abiotic stresses including heat, drought, and excess precipitation.
- Crops with high resistance to biotic stresses including insect pests, pathogens, and weeds.
- Crops with below-ground architectures and functional traits that improve nutrient and water uptake.
- Microbial or soil inoculants that reliably enhance nutrient uptake and increase crop performance, quality and/or yield.
- Crops that are optimized to benefit from modern farming practices, including architectural elements that enable higher populations, production, or narrower rows.

- Rice varieties that require less water and labor for production.
- Cotton varieties with increased fiber quantity and quality traits, including increased yield, fiber length, fiber length uniformity, fiber strength, and fiber fineness.
- Specialty crops with enhanced taste, flavor, and consumer appeal, with extended shelf life and less spoilage; specialty crops tailored for mechanical harvest.
- Sugarbeets with increased sugar content and improved stability during storage.
- Dwarfing rootstocks for the pear industry; smaller trees with greater early production; consumer eating quality, easier fruit ripening, reduced oxidative fruit browning over time.
- Tobacco varieties with enhanced input-use efficiency traits and selective chemistries.

Next Era Concepts

- Crops with stacked input-use efficiency traits including photosynthetic efficiency, nutrient-use efficiency, and water-use efficiency.
- Genetically enhanced microbiome that increases crop health and production including improved phosphorous uptake, nitrogen fixation around the root, enhanced water use, and biocontrol of pests and diseases.
- Crops optimized for different geographic regions, environments, and soil types.
- Custom or dynamic crops that display traits tailored to their specific environment and can adjust to variable weather conditions within and among seasons in response to pests, pathogens, or weather conditions while maintaining yield.

Gaps, Barriers, and Hurdles

Research - An advanced breeding toolbox is needed that greatly accelerates the breeding/trait development cycle for introducing multi-gene traits into elite crop germplasm of all crops. This includes easily deployed genome design platforms that engineer tens and hundreds of stacked traits into any crop or animal target, rather than focusing on individual traits and organisms.

Research - As we better understand the genetic components controlling yield potential, there is tremendous potential for improving crop production. For example, plant architecture of fruiting crops plays a fundamental role in determining potential yield; and advances in understanding the triggers of flowering and heterosis enable alterations in plant architecture that result in greater numbers of flowers, longer plant life, and greater yield. A gene-for-gene understanding of host plant versus pathogen interactions is needed to develop a deeper understanding of the genetics influencing plant/pest interactions, thereby enabling improvements in pest and pathogen resistance and control.

New modes of actions for herbicide tolerance and resistance to diseases and pests are needed, e.g., knocking out host-susceptibility genes that enable pathogenesis or engineering immune receptors that elicit broad spectrum resistance. Seeds need developed that perform better under challenging climatic conditions. Knowledge of genome regulation and emergence of phenotypes at various developmental and temporal scales is needed, including short-term circadian responses, stress adaptations and memory, and longer term phenological responses and adaptation. Modeling genome impacts on yield are needed to accelerate and predict potential outcomes of genomes prior to additional testing so that rapid progress in genome design goals can be attained.

Research - Reliable, automatic, multifunctional, and high-throughput phenotyping technologies, both above and below ground, are needed to enable phenomics-based research, which is defined as gathering of multi-dimensional phenotypic data at multiple levels from cell level, organ level, plant level to population level. Phenomics needs to combine agricultural innovation with crop phenotypic information in a high-throughput manner to associate phenotypes with underlying DNA sequence variation, with the goal of enabling phenomic selection to generate crops with desired traits. Breakthrough technologies and approaches are needed to connect above- and below-ground traits identified by high-throughput phenotyping, including the presence and activity of microbiome members.

Research - A fully indexed, global germplasm collection system, including wild relatives of modern crop species, is needed to support future crop development and GxExM analysis. The system should be fully genotyped and include global partners such as DivSeek and CGIAR, and public/private partnerships, such as the Germplasm Enhancement of Maize (GEM) project. Tools are also needed that enable rapid domestication of wild plants into new crops to meet specific needs, such as nutritional content, drought, and heat tolerance.

Research - Evaluate, develop, and optimize soil and plant microbiomes and crop genetics for crop vigor, resilience, yield, nutrient and water use efficiency, and soil health and carbon sequestration. Identify naturally occurring fungi or bacteria that promote phosphorus uptake and /or nitrogen fixation that might serve as inoculants. Investigate the effects of the management system, and genetic-environment effects on crop-soil microbiome interactions. Support and expand programs such as the National Microbiome Initiative, with the goal of developing a comprehensive understanding of plant, animal, and soil microbiomes to produce positive outcomes related to soil health and productivity, food safety and security, animal health, human health, climate change, and others.

Regulatory - For new innovations like gene editing, the global regulatory landscape is unclear; and there is a risk that genome-edited products will be brought under outdated, discriminatory, and highly burdensome regulator frameworks previously adopted for transgenic ag-biotech products, even though many of the newer products being developed using gene editing do not contain DNA from outside the plant's gene pool. This creates the potential for enormous barriers to entry for this emerging industry, potentially limiting the use of this game-changing technology to only a handful of companies and in only large-scale crops and applications. USDA should work with other Federal agencies and trading partners to help ensure a strong, science-based regulatory framework and harmonized international policies that support these products from development through commercialization. Find ways that new traits labeled as genetically modified organisms (GMO) do not get delayed in U.S. adoption because of international countries not approving them. The long delay and risk in international approvals is stifling investment into new traits and new gene editing techniques. Consider development of a national registry of all gene-edited products intended for agriculture and environmental use and submit information at both the open-field trial research stage and before putting products into commerce. Such a registry would ensure basic public transparency and monitoring by USDA, interested stakeholders, and the public.

Regulatory - The APHIS SECURE rule is a good first step to fostering innovation, but visibly absent were any revisions to the regulatory systems for future advances in non-plant GE organisms. As an example, the regulatory landscape is complicated for development and inoculation of GMO microorganisms. There is also some concern that the APHIS SECURE policy exempts large categories of gene-edited products without scientific evidence of their safety, which is likely to reduce confidence of our international trading partners.

Regulatory - USDA should establish policies and approaches to make gene editing technology broadly accessible and to ensure that it is used for societal benefit. It will be important to strengthen public breeding programs, develop open-source varieties, and enhance crop diversity and environmental, ecological, and public health outcomes. Without a holistic and thoughtful perspective on risks and potential impacts, innovations in genomic and precision breeding could contribute to damaging trends, such as the increased relative role of privately versus publicly funded breeding programs and consolidation in the breeding sector.

Other - Public acceptance is crucial for adoption and implementation of genome design tools and products, both here and abroad, and it is important to educate both producers and consumers about the benefits and safety of genome design solutions.

Digital and Automation

Incremental Solutions To Accelerate

- Satellite or remotely/proximally sensed data (e.g., drones or tractors equipped with sensors) that inform crop nutrient, water, and stress status.
- Ground-based sensors that inform soil nutrient and water status.
- Soil texture mapping.
- On-farm weather stations(s) informing local weather conditions.

Transformational Solutions To Create

- Suite of sensors that comprehensively scout and map a field for yield-limiting parameters including water or nutrient deficiencies and biotic stresses such as insects, weeds, or pathogens.
- Low-cost, digitally controlled precision placement tools such as robots, drones, or precision-ag machineries that deliver precise amounts of inputs or mechanically remove weeds.
- Robust, low-cost, on-farm digital networks and wireless systems with access to cloud-based computing that enable real-time data analytics and decision support tools.

- Sensors capable of distinguishing rice and red rice, coupled with automated methods of red rice control.

- Cotton gins with real-time processing flow monitors and controls that enable highly sensitive feedback loops to maximize gin performance, including energy usage monitors; sensors also enable detection and removal of foreign matter in the seed cotton to improve throughput and quality control.

- Cost-effective, automated harvesters for specialty crops, including fruit, vegetables, and the floral industry.

Next Era Concepts

- Broadly distributed, low-cost biodegradable sensors and biosensors delivering real-time data on nutrient and water status in soil and crops, with high spatial resolution.

- Diagnostic sensors and biosensors capable of detecting specific biotic and abiotic stresses including common pathogens, pests, heat stress, drought stress, and the combination of heat and drought stress, at high spatial resolution.

- Sensors that monitor below ground phenotypes and plant-related processes including root structures, soil microbiome, and microbial colonization of root systems.

- Sensors that identify and track pathogens and diseases coupled with a global tracking system that monitors movement of pests and diseases at the field, regional, and global level (e.g., Global Surveillance System).

Gaps, Barriers, and Hurdles

Research - Standards are needed for nutrient/water/soil measurements to enable design and implementation of interoperable sensors and decision support tools. Sensors and digital solutions should be scale-neutral, providing solutions for large farms, small farms, and urban farms, remain accurate and generate high-quality data in a variety of environmental conditions, and be affordable and available to all farmers. Developing sensors and digital ag technologies will require truly trans-disciplinary research among researchers and more trans-disciplinary training of students and workforce, with a proportionally higher investment in agriculture compared to e.g., energy, defense, and medicine.

Research - Emerging areas of research include biosensors and various nanotechnologies capable of detecting and diagnosing plant stresses and disease; biophotonic sensors, such as Raman spectroscopy, that measure molecules faster, more accurately, and more cheaply than existing chemical methods; detection of plant or insect volatiles that inform plant health and their local habitat; sensors embedded in soil or plants that are powered sustainably, for example, with miniature solar panels. These sensors will detect the presence of stressors or beneficials in real-time and could deploy or signal the deployment of precisely applied inputs.

Research - Broadband access in rural communities is essential for enabling the digital ag revolution. Prioritize and support a suite of “last-mile” connectivity solutions including wireline, mobile, and wireless to stimulate development of the most efficient and innovative solutions. Examples include TV White Spaces, Wi-Fly for beaming Wi-Fi from planes, High-Altitude Platform Stations (HAPS), etc. As an example, US Ignite, a non-profit organization dedicated to advancing the "smart community" movement, with partnerships from National Science Foundation (NSF), National Institute of Standards and Technology (NIST), and Department of Defense (DoD), are in the process of standing up a new rural wireless testbed to support research in novel technologies and architectures to reduce the cost of broadband delivery to rural communities. Includes autonomous or semi-autonomous vehicles and farming equipment and IoT-enabled precision farming, livestock and dairy management. Consider expanding programs like the Small Business Innovation Research (SBIR) Program or replicating the popular Innovation Corps (I-CORPS) programs at other agencies, with specific funding streams for wireless and connected technologies. Direct vehicle to vehicle networking standards also need developed, particularly in the absence of wireless infrastructure. For instance, The Ag Industry Electronics Foundation (AEF) has selected 802.11p-based standards as the basis of its vehicle-to-vehicle networking, and additional protocols are published under ISO 11783.

Research - Reduce the use of pesticides and improve the use of biologicals by targeting threshold levels of pathogens and pests and induce the plant innate resistance system, rather than focusing on killing the pathogen or pest. For pest monitoring and prediction, the most urgent need is a platform or hub system for entering and disseminating pest abundance/damage, and the latest evidence-based threshold and management information. Data for individual States/commodities are collected and shared already, but no national coordinated hub exists.

Other - Increase digital ag educational opportunities for farmers and future workers via support for education and extension.

Prescriptive Interventions

Incremental Solutions To Accelerate

- Usage of remotely sensed data, coupled with crop growth models and weather prediction tools, for targeted application of nutrients and water using precision ag machinery and variable rate irrigation/fertigation systems.

- Broader usage of enhanced efficiency fertilizers, with the goal of enhancing nutrient use efficiency while maintaining or increasing yields and reducing losses to the environment.

- Expansion of U.S. Wheat and Barley Scab Initiative and National Predictive Modeling Tool - Disease forecasting systems.

Transformational Solutions To Create

- Decision support tools that integrate real-time, on-farm data with crop/weather/soil models to recommend targeted treatments with high temporal and spatial resolution; products are deployed using 4R stewardship: right product, right rate, right time, and right place.

- Multi-spatial, multi-temporal simulation models that forecast crop and natural resources, assess risk, explore best management practices, and determine limitations and gaps and recommend specific interventions to maximize yield, profit, and environmental sustainability; e.g., integration of soil sampling, digital soil mapping, and assessing previous production spatially in each field to enable more economically sensible and agronomically predictable decisions.

- Prediction modeling tools for disease and disease management, with options for integrated pest management and improved plant protection products and methods of delivery (such as foams that reduce drift).

- Sensors on cotton gins that monitor and detect equipment fatigue, enabling predictive maintenance to prevent catastrophic gin failures.

- Improved aerial application systems that enable high-resolution spraying through integration of Global Positioning System (GPS), liquid and dry flow controls, on-board meteorological measurements, and pulse width modulation and improved pilot safety.

Next Era Concepts

- Decision support tools that integrate environmental and physiological data with predictive modeling to deliver precise amounts of nutrients/water/products at the individual plant level.

- Predictive modeling tools coupled with inducible biological processes such as epigenetics that enable rapid modification of crop traits to increase yield, quality, and resilience under changing in-season conditions.

Gaps, Barriers, and Hurdles

Research – High-quality data on field-based outcomes are needed for developing conceptual and predictive models that integrate the various components of the farm management system. Integration of data across these studies will require standardization of data collection, processing and analysis. Standards are also needed for development of interoperable tools and products. Data need to be collected from diverse spatial and temporal scales to better model and represent farm-level activities. For instance, collecting and processing soil data, including quantifying soil organic matter, nutrient testing, moisture, and microbial activity across geographies and cropping systems, will reveal deeper connections between soil measurements, crop production, and environmental outcomes. Artificial intelligence is needed to augment these protocols and reveal previously unknown relationships between various attributes and crop production. Up-to-date soil maps are also needed to inform data-based decision making. As the number of sensors in the system increases, consider Swarm Intelligence or Swarm Technology to increase the effectiveness and efficiency of prescriptive interventions.

Research - Cotton growers need help connecting data from all sources, including cotton production practices, cotton gin, and market data. Data fusion currently limits access to yield and sustainability enhancing technologies.

Regulatory - The regulatory environment in many ways discourages the reuse of waste material in the production of plant nutrient products. Currently, there is no Federal standard for "plant nutrition," each State regulates its meaning of "slow release," "nutrient efficiency," etc. This lack of a Federal standard can lead to difficulty in bringing new technologies that can positively impact the environment to the marketplace.

Other - Engage the private sector early in scientific discovery to fully realize the value of new discoveries with potential paths to value creation for farmers and consumers through public-private partnerships. Transparency is needed so the farmers know what "the black box" is doing. Open-access code would allow the validation and improvement of these tools. Tools also need to account for uncertainty, given that so many decisions made on a farm are made without knowing the final yield or price.

Other - To improve water use efficiency, support the development of affordable irrigation water meters that can be retrofitted to most common irrigation systems.

Systems-Based Farm Management

Incremental Solutions To Accelerate

- Build on ongoing public and private-sector development of data-driven field management strategies from sensor data to predictive models to increase crop production while minimizing inputs.

- Varietal selection and management by modeling GxExM with historical, aggregate data.

Transformational Solutions To Create

- Systems-analysis tools that integrate data across the farm including crop genetics, input costs and management, active farm sensors, geographic information systems, and weather that allows farmers to collect, analyze, and use data from their own fields to manage crop production precisely and profitably; tools should also consider the broader ag supply chain, allowing growers to project needs and estimate markets for commodities before a significant investment in crop production is made.

- Systems-analysis tools that integrate cotton gin data such as moisture and machine capacity with farm equipment data such as fuel use, spray patterns and crop yield, and fiber prices to enable real-time decisions between grower, consultant, equipment/applicator, ginner and accountant that maximize yield, quality, and economic benefits.

Next Era Concepts

Systems-analysis tools that recommend optimal crop management practices for a given field that take into consideration the interactions of all phytobiome components influencing yield, quality, safety, and sustainable production, ultimately enabling growers to manage seeds, biologicals, nutrients, soil, water, microbial communities and other phytobiome components with next-generation precision agriculture; the goal is to manage the outcome of the entire phytobiome, not individual phytobiome components.

Gaps, Barriers, and Hurdles

Research - Significantly more high-quality data are needed on the impacts and outcomes of various management practices to enable development of robust crop modeling and prediction tools. Data need harmonized and standardized across various sources to enable deep data analytics. The development of robust systems-analysis tools also requires deep and lasting collaborations between multiple scientific disciplines and alignment and partnerships between public and private sectors. These relationships should be openly and actively fostered. Many systems research studies require multiple years to study properly, and research grants should be funded for 5 or more years, as the 3-year grant cycle precludes long-term rotation research and obscures the long-term impacts of many ecological, economic, and social interactions crucial to success of ag systems.

Research - Adoption and implementation of digital ag approaches, and reaping their environmental and economic benefits, require incentives for adoption that are based on an understanding of the various factors that influence farmer decisions. The tools must be easy to use, and producers need education, training, and technical support, during and after implementation. What is needed, and really does not exist, is a resource to give farmers the tools and assistance needed to evaluate new technology and then integrate it into their existing management systems. The university extension system plays an important role here and should be supported in these efforts.

Research - Knowledge of what constitutes a healthy phytobiome will enable development of powerful new tools in the crop management toolbox. The phytobiome consists of plants, their environment, and their associated micro- and macro-organisms. These organisms, which may be inside, on the surface, or adjacent to plants, include a wide diversity of microbes (viruses, bacteria, fungi, oomycetes, and algae), animals (arthropods, worms, nematodes and rodents), and other plants. The environment includes the physical and chemical environment influencing plants and their associated organisms, and therefore the soil, air, water, and climate. Interactions within phytobiomes are dynamic and have profound effects on soil, plant and agroecosystem health. Understanding the interactions among the many components of an ag system represents a new vision for agriculture and sustainable agroecosytems management and increasing production capability. Best practices and standardized protocols are needed for analyzing data from phytobiome studies to enable deep analytics of combined studies. Train students and post-docs in disciplines that support the increased understanding of phytobiomes and their optimization in the farming ag system. Need approaches to sequence and/or modify the genomes of phytobiome constituents comprehensively, including both cultivated and uncultivated microbes.

Other - Advances in sensing technologies and data science can help translate the huge and rapidly growing body of agri-food system data into practical applications, and create an information commons that facilitates interdisciplinary research and the sharing of vital information amongst stakeholders. However, application of some aspects of these advances, especially AI and machine learning, to ag operations raises serious socio-economic and human questions, such as, "What are people for?" Turning more and more of the farming and ranching professions over to automated decision making could foreclose employment opportunities in rural America, limit opportunities for human creativity in ag and food system work, and even take human land stewards out of the process altogether. The impacts of these technologies on employment opportunities, rural economic viability, social capital, and quality of life must be thoroughly assessed. It is also important to conduct impartial, science-based assessments of potential unintended consequences of technological innovations. In particular, novel technologies that fundamentally alter or "engineer" complex ecosystem processes developed through 450 million years of co-evolution among land plants, animals, microbiomes, and their physical environments must be approached with utmost caution. For advanced technological innovation, a systems-based approach would ask not only "can this be done?" but also "should this be done, and if so how?"

Other - One of the key barriers to application of innovative solutions is gaining the trust of consumers in accepting these innovative solutions. Therefore, communication across the value chain about the value and benefits of these solutions will be critical. Youth education is essential (e.g., 4H and Future Farmers of America). As the next generation of agriculturalists, they will incorporate the concepts of reduced environmental impacts in their beliefs and practices now that will help pay off in the future.

Other - The goals of the Agriculture Innovation Agenda (AIA) are better understood as optimizing production rather than just maximizing production. The rigid numeric goals of the AIA regarding production and environmental stewardship should not be indicators of success for American ag. The promise of prosperity through high volumes of production has not delivered for U.S. family farmers and ranchers. Many have corn, soybeans, and dairy they cannot sell, which has pushed prices below the cost of production. The AIA should call instead for appropriate and profitable production of a safe and reliable supply of food and agricultural products to meet society's needs while bolstering farmers and their communities. The AIA would certainly help farmers, foresters, and ranchers, and the USDA needs to maintain experienced staff throughout USDA's agencies tasked with implementation of the AIA.

CROPS – PRODUCTION CAPABILITY

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

Genome Design

Incremental Solutions To Accelerate

- Expanded portfolio of cover crop options and improved cover crop germplasm.
- Improved and diversified forage species; for alfalfa and other forages, improved ability to grow on marginal, saline soils; improved drought tolerance, increased yield and protein content, pest resistance, greater digestibility, frost tolerance and winter survival.

Transformational Solutions To Create

- Crop varieties with improved below-ground traits, e.g., larger, deeper roots that store more carbon and enhance soil health and stability.
- Crop varieties that perform well in no till, reduced till, and are competitive with cover crops and weeds.
- Cover crops with value-added traits that increase environmental or economic benefits; e.g., cover crops that self-terminate before the cash crop is planted; cover crops with delayed germination that can be co-seeded with cash crop, germinating just prior to harvest; winter annual cash cover crops such as camelina or pennycress.

Next Era Concepts

- Deep-rooted perennial crops that store more carbon in the soil, reduce soil degradation, reduce water quality impacts from runoff, optimize and stabilize the soil microbiome, and help farms become more resilient to extreme weather events.
- High-value cover crops optimized for different regions, climates, and soil types.
- Soil microbiome that retains more carbon and produces less N_2O emissions.

Gaps, Barriers, and Hurdles

Research - Conduct plant breeding, selection, and cultivar evaluation within the context of advanced soil health management practices such as regenerative, conservation agriculture and other agroecological cropping systems to maximize soil and environmental benefits using crop genetics.

Research - Develop value-added cover crops for regional usage, such as systems that fit into the growing season of the more northern latitudes that struggle to have a cover crop established prior to a freeze.

Research - Consider novel uses of weeds, such as companion hosts that improve texture and nutrient base of soil, repel harmful insects, act as insect traps, etc.; consider harvesting some weeds for food or products; investigate weed genomics to identify genes that allow them to grow so fast and aggressively; use superweeds that have exceptional resilience to culture for food or soil benefit in extreme environments.

Regulatory - The APHIS SECURE rule was helpful in clarifying engineering of crop plants, but there is still significant uncertainty around application of genome design technologies for non-plant organisms, including the microbiome. Also need a regulatory framework for biostimulants, which is defined in the 2018 Farm Bill as "a substance or microorganism that, when applied to seeds, plants, or on the rhizosphere, stimulates natural processes to enhance or benefit nutrient uptake, nutrient use efficiency, tolerance to abiotic stress, or crop quality and yield."

Digital and Automation

Incremental Solutions To Accelerate

- Define "soil health indicators," especially those relevant to enabling Ecosystem Service Markets or Carbon Credit Markets, and establish standards for their quantification and reporting.

Transformational Solutions To Create

- Sensors that quantify, map and verify soil health indicators such as soil carbon sequestration, Green House Gas emissions (e.g., N20, CO_2), water quality, and soil biodiversity, including the microbiome.

- Sensors that quantify nutrient and water loss to the environment.

Next Era Concepts

- Broadly distributed, low-cost, biodegradable sensors and biosensors that quantify and inform soil health indicators with high temporal and spatial resolution.

- Broadly distributed, low-cost, biodegradable sensors that inform nutrient and water loss to the environment.

Gaps, Barriers, and Hurdles

Research - Develop and promulgate soil health testing protocols, including suites of tests that farmers can replicate easily and cheaply on cropland, grassland and forest land to understand, monitor and track changes in soil health. USDA should expand its work to identify key metrics for measuring healthy soils and protocols for testing, establish a clear set of protocols and standards that are consistent with AIA goals, and inform Ecosystem Service Markets and Carbon Sequestration Credit markets. Need to harmonize data collections, sample analyses, measurements and reporting for both public and private entities to aid efforts aimed at environmental improvements.

Research - Soil and forest carbon monitoring can be expensive, reducing profits and driving up carbon credit prices for consumers. Soil carbon is difficult to measure, and there is a need for increased investment in reliable and effective measurement/monitoring, reporting and verification technologies, as well as enhancing the COMET model with additional data so that farmers and forest owners do not need to independently undertake expensive monitoring to certify credits. Continue to populate the COMET model with more data and sites from across the country to establish credible carbon sequestration rates for all types and locations of forests and soils. Develop protocols to certify carbon credits for sale using COMET to determine sequestration rates, and thus reduce or eliminate the need for expensive monitoring.

Research - New sensors and technologies are needed for tracking water quality and measuring surface water flows to understand and model rate of movement through watersheds. Low-cost sensors are needed to assess the nutrient concentration in water for both surface runoff and subsurface flow through tile drainage systems. Research and model development are needed to enable farmers to gain personalized information for their fields to better understand and address nutrient loss both in-season and year over year. Sensors are needed for monitoring water quality, especially at the edge-of-field scale, to demonstrate the effectiveness of conservation practices that are being used in a field.

Prescriptive Interventions

Incremental Solutions To Accelerate

- Nutrient and water applications based on soil texture maps and infiltration models that minimize nutrient loss to the environment.

Transformational Solutions To Create

- Advanced field sensor technologies coupled with decision support tools that monitor soil nutrient cycling, plant-available moisture, and carbon sequestration dynamics, informing producer management decisions to realize the full benefits of improved plant genetics and soil microbiome to maximize production capability.

- Real-time data on soil health indicators and a suite of amendments, biostimulants and products recommended for improving soil health (e.g., on-farm manure use or other amendments that improve soil health, quality, and stability).

- Field drainage systems designed to recycle water and nutrients on the farm.

- Reduced nitrous oxide emissions from soils through a combination of enhanced efficiency fertilizers, altered microbiome with less N_2O production, and plants with improved nitrogen use efficiency.

Next Era Concepts

- Decision support tools that 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 with the goal of optimizing production capability and expanding ecologically diverse farming systems using regenerative farming practices.

- Multi-scale early warning network that links machine learning and open data with climate/risk indicators to enable tracking of vulnerabilities in agricultural regions and the potential for cascading events across landscapes and markets, helping all farmers and communities to better prepare and mitigate risks.

Gaps, Barriers, and Hurdles

Research - The largest challenge and opportunity for reducing nutrient loss to water is improving nutrient use efficiency on farms. This will require a better understanding of how nutrients cycle and are available for plant uptake and vulnerable to environmental loss, more accurate and accessible predictive and diagnostic tools to inform nutrient use decision making, innovative solutions for nutrient handling and application, and sound positive economic outcomes for farmers, as well as education and outreach to address farmer acceptance of new or different practices. Updated soil nutrient testing methods are needed that integrate the influence of plants, soil biology, and the microbiome on nutrient retention and recycling. Testing includes improved lab-based methods that are inexpensive and rapid, and paired with low-cost, scale-neutral technologies and in-field sensors that monitor water, nutrients, and carbon through space and time. We also need better modeling of ground water use and recharge, particularly as it relates to the broader segments including cities, farms and industries. Biobased enhanced efficiency fertilizer is an emerging technology that repurposes ag byproducts and holds potential to reduce nutrient loss and improve soil health, and positively impact downstream water quality. However, current pathways to analyze novel products and technologies into existing USDA tools and environmental models are time consuming and unclear. Standardization of testing processes and data validation is needed to develop interoperable decision support tools, which in turn can be adopted by farmers and ag retailers to advance science-based sustainability outcomes.

Research - The fastest way for our soils in the United States to regain soil health and sequester 2-3 times greater quantities of soil organic carbon than with typical conservation management approaches will be to adopt a system of pasture-crop rotations with modern conservation management strategies - not a return to widespread soil exposure with tillage. Pasture cropping using native grasses as perennial cover and grazing of ruminants increases economic and environmental benefits of land use. These practices enhance soil and water quality, reduce runoff, and provide additional income through grazing.

Research - Need more farmer-led, on-farm research on best management practices for soil health, to identify what suites of practices perform best in various soils, climates, and ag systems. Such studies could be supported by expanding programs such as the Sustainable Agriculture Research and Education (SARE) grant program.

Research - By obtaining a wholistic understanding of the phytobiome and phytobiome health, it should be possible to rehabilitate marginal, degraded and depleted lands world-wide to expand arable lands and sustainable food production.

Regulatory - Public policy needs more fully aligned to reward farmers for environmental outcomes of farming while increasing productivity and farm output quality. Need a clear definition of "biostimulant" and regulatory policy that supports innovation, consistent product labeling, and clear and reasoned criteria for product efficacy, safety, and composition.

Systems-Based Farm Management

Incremental Solutions To Accelerate

- Crop rotations that improve soil health, soil quality, and reduce weed and pest pressures.
- No-till or low-tillage practices.
- Broader cover crop use.
- Usage of prediction models developed with national aggregate data to select cover crops, crop rotations and/or management practices that increase economic and environmental benefits.
- Incentives for adopting innovative, regenerative farming tools and practices through USDA Natural Resources Conservation Service conservation programs (e.g., Environmental Quality Incentives Program (EQIP), and Conservation Stewardship Program).

Transformational Solutions To Create

- Expanded usage of cover crops, double cropping, crop rotations, perennial crops, silvopasture, etc., that provides producers with additional economic and environmental benefits; e.g., highly productive perennial grain or bioenergy crops that augment existing ag systems while decreasing tillage, reducing erosion, enhancing ecosystem services, improving microbial diversity and soil health, and keeping nitrogen from leaching out of the soil while supplying more nitrogen to subsequent crops.
- Expanded use of environmental land buffers that capture and reduce nutrient loss to the environment, increase carbon fixation, serve as wind breaks, and increase biodiversity, including beneficial insects and biocontrol organisms.
- Systems-analysis tools developed with regional, aggregate data to select crops, cover crops, crop rotations and/or management practices that maximize economic and environmental benefits.
- Expanded incentives for adopting innovative, regenerative farming tools and practices through, e.g., NRCS programs, Ecosystem Service Markets, and Carbon Credit Markets.

- Incentivized on-farm production of energy (e.g., agrivoltaics, biogas, wind farms) that reduces net carbon emissions and farm waste while maximizing production and environmental benefits.

Next Era Concepts

- Whole-farm modeling using high-quality, farm-scale data to select a diverse array of crops and management practices that maximize environmental and economic benefits and enable farmers to significantly change their farm system based on changes in climate.

- Expanded incentives for adopting innovative, regenerative farming practices through programs such as NRCS, Ecosystem Service Markets, and Carbon Credit markets that consider additional criteria such as nutrient recycling on farms, increased biodiversity, and production/usage of renewable energy.

Gaps, Barriers, and Hurdles

Research - Systems-based farm design should consider practices that improve soil health, advanced grazing management, cover crops, diversified cropping systems, crop-livestock integration, agroforestry, silvopasture, on-farm and food system energy efficiency, on-farm renewable energy production, and other climate friendly practices. Reducing agriculture's environmental footprint requires forward thinking innovation that supports wider adoption of alternative, less intensive practices and crops. This does not imply that we need to reduce our commodity crop acreage, rather it supports the urgency for integrating diversity into our rotations and systems that will also enhance productivity. On-farm energy production systems such as solar, biogas and wind farms should be analyzed using life-cycle analysis to ensure economic, social, and environmental benefits. Robust economic models are needed for value capture of new crops to gain grower acceptance. Promote a more circular economy and help where possible on end-of-life disposal issues for plant-based products, such as composting or recycling infrastructure.

Research - More research is needed to understand the ecological underpinnings of farms and how agriculture can be designed at various scales to enhance ecological functions of the landscape. With increased resolution and ability to detect smaller zones comes the possibility to be able to show the environmental effect on what is happening under the ground. How do soil management practices directly impact the environment, water, and nutrient levels in the field? Increase the understanding of soil-plant-microbial interactions and how to adjust management practices to optimize those interactions for maximum productivity, minimal environmental impacts, and for production and economic resilience in the face of climate change and market volatility. Also need to better understand and quantify carbon sequestration and productivity potential, given the interaction of varying soil types, weather, and agronomic/cropping system practices, and to improve water quality specifically by understanding plant nutrient uptake, timing, application rates, and placement. As sustainable ag intensification increases, contamination of soil and water resources is high. Need to better understand transfer pathways of contaminants from soil and water resources to food, and human exposure to contaminants. Examples include contaminants such as pharmaceuticals and per and polyfluoroalkyl substances and understanding their distribution in agroeceosystems and their risks to animals, plants, and humans. Mitigation strategies need developed to minimize such risks, including both technological and policy solutions. Need to quantify nutrient loss pathways linked to emerging and existing fertilizer management practices across all crops, cropping systems and geographies to better understand the interactions of cropping systems management and genetics on nutrient loss and improved uptake by the plant; e.g., the Nutrient Use Geographic Information System (NuGIS) program aggregates county and watershed level data to spatially interpret nutrient balances, efficiencies, and regions where ag productivity and environmental quality can be focused upon. Need research that integrates multiple datasets and compares the promise of regenerative ag against actual agroecosystem performance across different performance areas. Outcomes could include smarter incentives for ecosystem services programs that compensate farmers for achieving measurable outcomes.

Research - Additional research is needed to better understand the benefits of silvopasture and agroforestry. Agroforestry practices such as windbreaks and shelterbelts utilize linear planting of trees to provide economic and environmental benefits for ag producers by mitigating the effects of winds while improving conditions for soils, crops, livestock, wildlife, and communities. Windbreaks help protect crops from damaging winds, prevent soil erosion, increase crop yields, and pollinator habitat, and provide relief for livestock from harsh weather conditions that can affect animal productivity due to increased stress and mortality rates. Through tree plantings and incorporating agroforestry practices into their operations, ag producers can diversify their production systems and sources of revenue, enhance ag production, and sequester carbon while providing numerous environmental benefits including clean air, enhanced water quality and quantity, and improved wildlife habitat and biodiversity, including pollinators. Expanded implementation of stream restoration and riparian forests near ag production systems reap multiple environmental and economic benefits including enhancing water quality, filtering and absorbing pesticides, bacteria, and sediments and curbing other pollution such as nitrate stemming from ag production. Riparian forests also allow precipitation to be absorbed and released slowly into rivers and streams over time, reducing erratic flows that contribute to down-stream flooding. During flood events, buffers reduce the velocity of water, allowing more water to infiltrate into the soil and recharge ground water. To foster biodiversity, invest in landscape diversification as well as crop diversification - understanding the economic and social implications as well as agronomic opportunities of such structures as hedge rows, wind breaks, presence of polyculture plantings, conservation easements, and habitat strips, among others. Need to strengthen and broaden the USDA Climate Hubs, establish regional agroforestry centers, and expand funding for the Cooperative Extension System. Expanded outreach and tech transfer should also embrace social considerations, including racial equity, establishing the next generation of farmers, human health outcomes (optimizing nutritional value per acre), integration of urban and nearby communities, and farming and non-farming populations.

Research - Need affordable, accessible, scale-neutral conservation equipment such as no-till drills, strip-tillage bars, no-till transplanters, cover crop seeders, non-chemical termination implements such as roller crimpers, multi-purpose machinery that can be used to plant, cultivate, or harvest multiple crops with minimal alterations. Need highly efficient tractors and scaling up of electric vehicles and ensuring they are competitively priced with combustion engines.

Regulatory - Funding and risk management needs to evolve to embrace new farm management innovations. Farm subsidies and farm program hurdles that prevent extended crop rotations and/or restrict the use and timing of cover crops need to be adjusted. Crop insurance programs must be flexible enough to consider practices like cover crops. Land idling programs such as the Conservation Reserve Program (CRP) and conservation easement programs that restrict land use, such as the Agricultural

Conservation Easement Program (ACEP), should be targeted narrowly to avoid restricting farmers and ranchers' access to productive ag land. Need to carefully balance these programs with programs such as the Environmental Quality Incentives Program (EQIP) and the Conservation Stewardship Program to ensure that ag production needs are met while at the same time benefiting the environment. Review existing conservation policies under USDA programs and connect with carbon markets or incentives for ecosystem services programs to generate revenue for farmers and incentivize practices that provide clean air and clean water, as well as nutritious food. Review the opportunities to include soil organic carbon and/or soil health testing as a standard part of every conservation contract funded and provide incentives to farmers to carry out annual soil health testing. Results should be reported to the participant, USDA, and landowners, so the agency can begin to collect practice-specific data on the impacts over time of the conservation practices it funds.

Other - With today's advancements in science and technology, it is possible to completely decommoditize the system of ag to bring about meaningful change for growers, consumers, and the planet. In this evolution, the economics of farming are vastly improved, giving farmers increased market power, premium at harvest, and data-based agronomic information that enables agricultural carbon sequestration - putting us on a new trajectory toward meeting USDA's environmental goals by 2050. The farm ag system provides many valuable benefits, including ecosystem services, nutritious food, and jobs in rural communities. Paying farmers for using their land wisely, for example, sequestering carbon and capturing water, will increase a farmer's bottom line while adding resilience to extreme weather. A carbon credit system would allow farmers to generate and sell greenhouse gas emissions reductions credits based on their embrace of innovative and advanced soil management practices that sequester atmospheric carbon. The opportunity for farmers to reap massive benefits from this type of system is evident, as scientists have estimated that nearly half of the climate mitigation potential of agriculture is derived from soil carbon protection, sequestration, and other agricultural GHG emissions reductions derived from similar management practices. As examples, the Bipartisan Policy Center, Farm and Forest Carbon Solutions Initiative, is supporting development of policies that support farmers, ranchers, and foresters in implementing practices that sequester carbon while also providing economic and environmental co-benefits. The Ecosystem Services Market Consortium's market will financially reward farmers and ranchers who voluntarily adjust crop and livestock production systems in ways that increase soil carbon sequestration and retention, reduce GHG emissions, improve water quality, conserve water, and provide many additional ecosystem service outcomes, such as enhanced biodiversity and habitat conservation. These markets require standardized, quantified outcomes, and allow the attributes or credits to be sold in a national ecosystem services market to entities seeking to reduce their environmental footprint. There must be clarification and standardization of the technical guidelines for quantifying greenhouse gas emissions and carbon sequestration at the entity-scale for agriculture and forestry, or "Blue Book." It is important to support and engage multiple groups and organizations as markets are being considered and developed, including NGOs, universities, and public service organizations. Agencies might also consider offering free conservation product labeling for ag products that are produced in verifiably sustainable ways. This would allow producers to differentiate their ag products that were produced in ways that meet conservation goals of reducing soil erosion, maintaining or enhancing soil quality, improving water quality, and managing the quantity of water available for irrigation, all of which benefit the environment and local communities. Incentive structures such as tax incentives, grants and cost-sharing partnerships need developed to further encourage the adoption of new and/or improved practices and systems to reduce environmental impacts.

Other - Agriculture is part of the environmental solution, and it will be important to educate the public by increasing citizen science literacy, farm-to-table knowledge, more 4-H programming, and hands-on experiential learning such as educational museums and demonstration farms. We need to educate farmers, producers, and consumers on benefits of regenerative agriculture; as an example, expand and leverage the work of existing education groups such as Kiss the Ground. Farmers, foresters, and ranchers also need education and support on the usage and functions of systems-analysis tools; these tools should be scale-neutral and available to everyone.

Other - Incentivize and leverage the ingenuity of farmers for on-farm innovation. For example, a farmer receiving support through EQIP for implementation of a specific practice could be incentivized to innovate further and achieve greater productivity and environmental benefits than anticipated.

CROPS – MARKET EXPANSION AND DIVERSITY

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

Genome Design

Incremental Solutions To Accelerate

- Crop varieties developed for diversified end-use markets (e.g., food, feed, biofuel, bioproducts, etc.).
- Crop varieties selected for organic practices including increased yield potential.
- Cotton varieties developed for diversified end-use markets (e.g., food, feed, biofuel, bioproducts, etc.) while maintaining high-quantity and -quality fiber traits.
- Specialty crop varieties selected for diversified end-use traits and markets (e.g., consumer appeal, nutrition, cultural or regional markets).

Transformational Solutions To Create

- Crop varieties with specific, high-value end-use traits (e.g., nutraceuticals, nutritional content, consumer preferences, optimal animal feeds, biofuels, bioplastics, biodegradable packaging materials, etc.)
- Crop varieties optimized for organic production, e.g., with enhanced below-ground traits that maximize nutrient use and improve soil health and stability.
- Regionally specific crops that are produced and distributed through local food systems.
- Soybean varieties tailored for various end-use industries (e.g., high oleic soybean oil for improved health, better shelf life and stability at high temperatures; high omega-3 oil for aquaculture feed, with ponds located near to end-users to reduce transport costs; optimal animal feeds, biofuels, bioplastics, etc.).
- Cotton seed with value-added end-use traits including improved human lipid profile (e.g., dihydrosterculic acid) of seed oil, improved amino acid profile and oil content for animal feed, and additive/alternative feed for aquaculture, with no detrimental changes in fiber quantity and quality traits.
- Specialty crop varieties optimized for vertical farming with traits including easy and uniform fruiting, rapid biomass and multi-harvest capable crops, photoinduced quality, auto-harvest friendly traits, and dwarf plants with yield efficiency.

- Hemp varieties developed for food, feed, pharmaceutical, nutraceutical, industrial products, and feedstock ingredients; varieties developed as rotation crops, windbreaks, phytoremediation, carbon sequestration, and forage.

- Crop varieties optimized for production of plant-based protein products with traits conducive to desired flavor, texture, and nutritional content.

Next Era Concepts

- Crop varieties with high-value end-use traits (nutraceuticals, nutritional content, consumer preferences, optimal animal feeds, biofuels, bioplastics, etc.) combined with input use efficiency and regenerative farming traits.

- Regionally specific crops with high-value traits such as improved nutrition, flavor and health attributes combined with sustainability traits and tailored for shorter supply chains.

- High-yielding cotton varieties with custom-designed fiber quality traits meeting end-use market demands.

- Cotton seed with high-value end-use traits combined with input use efficiency and regenerative farming traits, with no changes or increases in fiber quantity and quality traits.

Gaps, Barriers, and Hurdles

Research - Transdisciplinary collaborations between agricultural scientists, economists, and social scientists are needed to identify traits that would add value from a societal or cultural perspective, including underrepresented communities.

Research - As global demand for protein increases, expand the design and production of plant-based protein products that complement animal proteins and meet consumer demand. Identify and engineer microbes to aid in production of protein products, either directly or indirectly through production of growth factors, which are currently among the primary cost drivers for cultivated meat production.

Research - Expand the marketing opportunities for plant-based products; e.g., expanded usage of crop-based feedstocks for biofuel and bioproducts production, including cellulosic ethanol, crops optimized for biodiesel production, biogas, jet fuel, and other post-harvest treatments such as thermotropic conversion, and cracking and reforming to produce higher value chemical feedstocks. Use plants as bioreactors to produce high-value chemicals such as pharmaceuticals and nutraceuticals. Implement biotechnology to expand production of biobased products such as bioplastics, as well as expanding post-harvest opportunities for using plant-based feedstocks for manufacture of biobased products (e.g., soybean oil into tires and asphalt sealants). Increase use of non-food parts of plants (e.g., cobs, stems) or removing compounds from non-food ag products that can be used for food (e.g., non-food seeds to oil). Life cycle analysis database of ag-related feedstocks and products to stimulate the bioeconomy.

Regulatory - Increase support for Federal policies and programs such as the Renewable Fuel Standard, Clean Fuels Deployment Act, biofuel tax credits, USDA Biofuel Infrastructure Partnership program, and the Energy Title in the Farm Bill to help the biorefining industry gain market share and continue to innovate. Support increased usage of renewable fuels and higherlevel blends of ethanol and biodiesel and continue to support biobutanol development. Expand the infrastructure to increase higher blends of ethanol sales. From a legislative standpoint, building on the success of the Renewable Fuel Standard with a Low Carbon Octane Standard (LCOS) would be an effective means of maximizing carbon reductions from transportation in the near- and mid-term and would minimize impacts to low- and middle-income families, create family sustaining jobs, and advance environmental justice. Another example of legislation driving innovation is the California Low Carbon Fuel Standard (or LCFS), which has shown that carbon pricing can drive technology innovation and emissions reductions. Most of the barriers that discourage broader expansion of higher ethanol blends are regulatory in nature and under the jurisdiction of EPA. The USDA is encouraged to work with EPA to address key regulatory barriers and impediments. Additional research is required to develop mechanisms to capture and sequester the biogenic carbon dioxide produced during the fermentative production of ethanol.

Digital and Automation

Incremental Solutions To Accelerate

- Broader implementation of digital tools to improve identity preservation from field to market.
- Broader use of sensors that inform product quality and safety from field to market.

Transformational Solutions To Create

- Use of blockchain or similar digital technology with full product traceability from farm to fork.
- Diagnostic sensors that monitor product quality, nutritional content and safety, including detection of specific pathogens, throughout the food production system.
- Digital/automated solutions that address labor choke points and increase product and worker safety.
- Specialty crops: Controlled environment systems (e.g., vertical farms) that allow precise and automatic control of environmental variables, nutrient, and water to optimize crop production.

Next Era Concepts

- Fully integrated traceability and product monitoring system that ensures both identity preservation and maximizes product quality and safety, from farm to fork.

Gaps, Barriers, and Hurdles

Research - Increased demands for traceability and transparency in food/agriculture have prompted a major shift in interconnecting the ag supply chain through technology. This will only intensify as production chains shorten. Further, the digital story must begin well before planting, including the sustainable farming practices used in the production of food/ag products that serve as the "first chapter" in the provenance story going forward. Data and Internet of Things (IoT) have the capability to help growers capture additional income and even go directly to the consumer by allowing transparency in the supply chain.

Research - Sensors combined with Artificial Intelligence in food processing hold great potential to improve nutrition, sustainability, reduce waste and improve quality. Need a range of sensors that include contact and non-contact sensors that function in a range of challenging environments and conditions to monitor product quality and safety.

Research - Automated solutions can be used to address many labor challenges, especially where repetitive or otherwise dangerous tasks predominate. They also support sterile production systems and usage of controlled environments. Lower cost and/or higher return on investment automated solutions are needed to facilitate broader adoption and implementation. Solutions should also address the labor challenges of small, medium, and large operators alike. It is important to assess technologies well before they are developed with public funds and released to determine who is likely to benefit, and who will be hurt; for instance, new technologies should be thoroughly vetted to avoid negative unintended consequences, both ecological (e.g., impacts of gene-edited organisms on agroecosystem function) and social (e.g., technologies that further promote consolidation resulting in loss of jobs and economic opportunity).

Prescriptive Intervention

Incremental Solutions T Accelerate

- Production practices and interventions that increase yield of organic crops.

Transformational Solutions To Create

- Decision support tools that couple real-time monitoring of products throughout the ag production chain with recommended treatments that minimize loss and maximize safety.

- Identify areas along the food production chain where rapid changes and interventions can be implemented to re-route or re-distribute food rapidly when market accessibility changes.

Next Era Concepts

- Production, manufacturing, distribution, and storage systems supported by AI and blockchain-type technology that enable tracking of product's physical, chemical, and microbiological properties and provides predictive ability for safety, risk, and quality control at all scales.

Gaps, Barriers, and Hurdles

Research - Major areas for research and development for the organic industry, which also likely have cross-over to other areas of ag production, include manure and compost safety, methods for increasing biodiversity and pollinator health in ag systems, methods for increasing soil health, development of ag practices that reduce greenhouse gas emissions and contribute to climate change mitigation, research to develop innovative pest control methods that support pollinator health, the inclusion of socioeconomic considerations in future research, and methods for increasing yields. Techniques for supporting pollinator health include crop rotations, hedgerow planting, and the use of IPM techniques. Need to refine GHG models such as COMET-farm, dentrification-decomposition (DNDC), and Greenhouse Gas Reduction through Agriculture Carbon Enhancement Network (GRACEnet) to provide accurate model outputs for organic systems to help organic producers minimize the GHG footprint of their production systems.

Regulatory - Substantial transportation efficiencies and other forms of transportation cost savings can be gained through regulatory reforms. Through these cost savings, U.S. producers would receive higher prices for their ag commodities. Modernize U.S. locks and dams to enable the use of larger, more cost-efficient tows. Urge the USDA Agricultural Marketing Service, Office of Transportation to continue and expand its role as a strong and effective advocate on behalf of U.S. ag concerning the regulation of railroads at the Surface Transportation Board and the regulation of motor carriers and truck drivers at the U.S. Department of Transportation.

Systems-Based Farm Management

Incremental Solutions To Accelerate

- Diversified farm systems that provide multiple marketing opportunities to reduce risk of economic loss from environmental and/or market instability.

Transformational Solutions To Create

- Systems-based models and decision support tools that integrate data across the ag production chain and consider end-user demand, market incentives and shortened supply chains to improve design and profitability of diversified farming systems.

- New uses and marketing opportunities for visually unappealing produce that is otherwise nutritious and safe, leading to reduced in-field losses.

Next Era Concepts

- Scale-neutral, comprehensive farm modeling system that integrates across the ag production chain and includes social and regional considerations that allow for selection of diverse crops, animals, and management practices that maximize economic, environmental, and societal benefits.

- Taking a systems approach to the continuum of soil, plant, animal, and human health, seeking to maximize nutritional value per acre and not simply yield per acre.

Gaps, Barriers, and Hurdles

Research - As consumers, physicians, and nutritionists grow to see food selection as a means of preventing or minimizing chronic diseases, demand for the production of specific crop varieties will increase, and consumers are already demanding more locally grown options to reduce the environmental footprint associated with transportation. Urban ag provides one option for meeting many of these consumer demands, but requires significant R&D (research and development) and support. Urban farms offer new and exciting opportunities to leverage population density for a more efficient, circular economy of waste and re-use (e.g., composting) while also providing jobs and ag education opportunities in city centers. CO_2, greywater, heat, and compost from urban environments can be utilized by nearby urban farms, and these farms can provide increased carbon sequestration, cleaner air, mitigation of the heat island effect, greenspace, and a reduced risk of flooding through improved water retention in soil. Vertical ag systems also offer a solution for producing local food using indoor digital ag technologies that eliminate the impact of weather changes, accelerate growth cycles, use fewer natural resources, and produce food with a smaller environmental and acreage footprint. As supply chains shorten, localized food production, processing, and storage systems are needed for both urban and rural environments. Need to help family farms modify operations so they can sell direct to local communities, restaurants and grocery stores, as well as directly to families via farm stands.

Research - Approximately 20 percent of produce in the United States does not leave the farm due to being aesthetically unfit for grocery store shelves (often termed "ugly" produce), and 32 percent of total produce calories are lost or wasted during production, handling, storage and processing stages. Research is needed to develop alternative uses and re-capture these lost resources; e.g., consider the use of brining technologies to extend the lifetime of fruits and vegetables to reduce food loss and waste.

Research - To determine the most impactful innovative solutions in the farm production system, it is important to standardize methods and evaluate technologies. As an example, groups such as UPL's OpenAg Center are partnering with promising start-ups to characterize and bring new technologies to market. The OpenAg Center consists of seasoned, sought-after scientists to quickly validate a wide range of technologies. The goal is to break down traditional barriers to entry and significantly speed the process of getting new technologies tested, approved, and out in the field for adoption. These types of partnerships, including public/private/government, coupled with clear standards and measures, would help stimulate the innovation ecosystem.

Regulatory - Organic farming and organic products can bring a premium to farmers, but there is no single Federal program at USDA to assist farmers with managing the process of transitioning to organic. USDA could help support the organic transition process for new, beginning, and current farmers by expanding existing financial risk management programs offered by the USDA Risk Management Agency and the USDA Farm Service Agency.

Regulatory - Public sector research should drive toward generating actuarial data that demonstrates how systems approaches contribute to productivity and environmental benefits. Decision-useful data for crop insurance programs could be a key output. Public sector research should be intentionally designed in such a way to generate data that can be used by policymakers and the private sector to support a just transition for farmers to advanced management systems.

Other - For all innovations, effective education/marketing programs are needed to help farmers and consumers understand why systems-level improvements are needed, and how these new technologies and practices will benefit farmers, the environment, and society at large. Communication is key to bridging misconceptions and advancing us into an equitable and sustainable agricultural innovation-based future. A promotional campaign designed around public benefits related to USDA-sponsored solutions could help improve public awareness of the value of the USDA and how agricultural research positively affects communities, both urban and rural. A coordinated agritourism effort could shed light on how science and technology can help tell the story of sustainability in the context of food, fuel, and natural resource management. This effort cannot only provide our Nation's producers with the capability to share stories but also reinvigorate the capability for cooperative extension and the State ag extension system to narrate their history to an interested public while providing a vision for the future that is aspirational. A nationwide "America's Fair," celebrating agricultural innovation across these local and State entities, could provide a unifying event celebrating the dynamic and evolving history of agriculture in our country in a way that reflects and looks forward with possibility.

Other - We must foster an innovation ecosystem that unleashes the transformative potential of science and take steps to ensure the gains from these innovations are broadly shared for the benefit of all humanity. Strong support of land-grant universities and Historically Black Colleges and Universities will be critical to produce and develop young scientists and engineers critical to moving the industry forward. Improve availability and accessibility of data, tools, and models for Black, Indigenous, and People of Color (BIPOC) and other underserved farmers to establish and maintain farming operations while also boosting the next generation of farmers. Ensure that these tools and models are informed by these communities, and that they are designed with both sustainability and food security in mind. Innovations should embrace social considerations, including racial equity, establishing the next generation of farmers, human health outcomes (optimize nutritional value per acre), and integration of urban and nearby rural communities, and farming and non-farming populations. Innovation flourishes when science and consumer values are aligned and complement one another, and the public sector needs to help lead the way in setting goals for systems-based initiatives. Need to prioritize understanding consumer preferences and planning for shifts in consumer demand.

Other - Statistics show that the ag workforce is shrinking and aging; it is important to develop and train the next generation of farmers, foresters, and ranchers. The opportunities are there, but a high-tech, rural workforce must be developed. The agricultural workforce must grow from temporary ag workers and farm owners to include "smart farming" engineers and researchers.

Other - The USDA is encouraged to develop an Agriculture Innovation Agenda (AIA) that keeps priority goals clearly in focus: soil health, water and nutrient efficiency, resilience and yield stability, economically viable farms and rural communities, climate stabilization and other ecosystem services, and food security. The AIA must prioritize innovations that service family farmers and ranchers, the public good, and environmental health, and not simply "high tech" for its own sake or even greater degrees of automation demanded by the largest scale agribusiness operations. USDA is encouraged to provide equitable access to research programs and technical assistance and ensure its programs are explicitly designed to benefit diverse ag sectors, and communities and regions that may be especially vulnerable to the effects of climate change and drought, and producers from historically underserved populations. An imbalance in Federal investments is the greatest barrier to a resilient and healthy food system. Federal resources should broadly support underserved producers, holistic soil-building practices that sequester carbon, on-farm conservation programs, meaningful risk management opportunities, research on non-chemical pest control methods, regionally tailored public seed and animal breeding programs, and public education and marketing to help consumers prioritize health and the environment in their food choices.

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.

Genome Design

Incremental Solutions To Accelerate

- Population surveys that reveal genetic variation and associate genetic variation with environmental adaptation and phenotypic variation.
- Long-term research and monitoring plan that evaluates ecological impacts of introducing genetically improved trees into natural forest ecosystems or plantations.
- Dedicated tree breeding centers to facilitate and accelerate genetic improvement processes.

Transformational Solutions To Create

- Germplasm resistant to insects, diseases, and abiotic factors available for all tree species of commercial value (e.g., loblolly pine and Douglas-fir).
- Germplasm resistant to insects, diseases, and abiotic factors available for all tree species of ecologic value that are at risk of extinction without improved germplasm; as well as other affected species deemed of significant importance by stakeholders and USDA – that will help provide ecosystem services and benefit human health.
- Genetically robust populations of native tree species used for urban forests.

Next Era Concepts

- Microbiome that is optimized for forest health, productivity, and resiliency.
- Genome sequence and associated data for the 900-plus U.S. tree species to aid in genetic conservation and recovery efforts to maintain healthy, diverse forests and associated ecosystems into the foreseeable future.

Gaps, Barriers, and Hurdles

Research – Expand investment in genome sequencing of forest tree species, beginning with those currently threatened by exotic pests and diseases as well as those of major commercial importance. Develop reliable reference genomes, and high density genetic and physical maps of forest trees, to enable research and applications related to the forest health and productivity. Genome sequences provide a foundation for understanding gene complexes, the interaction of genes with the biotic/abiotic stresses, annotation of genes, molecular breeding and conservation of genetic resources.

Research - Forest breeding programs should include the collection and preservation of germplasm; species-specific research and breeding tools; identification and selection of desired traits such as resistance to diseases and pests; production of sufficient numbers of propagules; site preparation, planting and maintenance protocols; and strategies for management and restoration. The proper mix of species and genetic diversity will be key to long-term success of programs such as the "Trillion Tree Initiative," Develop a better understanding of how tree genetics affects pests and pathogens. Consider the impacts and risk of using extensive monoculture species in areas such as the Southern United States, and how best to minimize any risks in the future. Improve tree breeding and selection technologies to accelerate the timeline for introduction of new traits. For priority tree species of commercial value and threatened species of ecologic value, accelerate establishment of breeding programs in conjunction with genome design to ensure the most appropriate germplasm is available for use in technology design and that technologies, once developed, will actually be applied.

Research - A better understanding of the forest soil microbiome is needed to develop strategies for leveraging plant-microbe interactions for improving forest health, resilience, and carbon sequestration. In addition, understanding the dynamic interactions between all "phytobiome" components will greatly expand the number of tools in our crop/forest management toolbox. Phytobiomes consist of plants, their environment, and their associated micro- and macro-organisms. Plants evolved in association with diverse macro- and microorganisms and depend on them, much as humans depend on their elaborate microflora for short- and long-term health. These organisms, which may be inside, on the surface, or adjacent to plants, include a wide diversity of microbes (viruses, bacteria, fungi, oomycetes, and algae), animals (arthropods, worms, nematodes and rodents), and other plants. The environment includes the physical and chemical environment influencing plants and their associated organisms, and therefore the soil, air, water, and climate. Scientific tools are now available to probe deep into phytobiome networks and generate systems-level knowledge that can be exploited for optimizing the health and productivity of plant-based ecosystems.

Research – Develop a gene for understanding host plant versus pathogen interactions to develop a deeper understanding of the genetics influencing plant/pest interactions, thereby enabling improvements in pest and pathogen resistance and control. Develop new modes of actions for tolerance and resistance to diseases and pests, e.g., knocking out host-susceptibility genes that enable pathogenesis or engineering immune receptors that elicit broad spectrum resistance.

Research – Develop reliable, automatic, multifunctional, and high-throughput phenotyping technologies, both above and below ground, to enable phenomics-based research, which is defined as gathering of multi-dimensional phenotypic data at multiple levels from cell level, organ level, plant level to population level. Phenomics needs to combine AI with tree/plant phenotypic information in a high-throughput manner to associate phenotypes with underlying DNA sequence variation, with the goal of enabling phenomic selection to generate crops/trees with desired traits. Breakthrough technologies and approaches are needed to connect above and below ground traits identified by high-throughput phenotyping, including the presence and activity of microbiome members.

Research - Evaluate, develop, and optimize soil and plant microbiomes and tree genetics for tree vigor, resilience, yield, nutrient and water use efficiency, and soil health and carbon sequestration – and notably for future predicted climates in mind that long-lived tree species will face. Identify naturally occurring fungi or bacteria that promote phosphorus uptake and /or nitrogen fixation that might serve as inoculants. Investigate the effects of the management system, and genetic-environment effects on tree-soil microbiome interactions. Support and expand programs such as the National Microbiome Initiative, with the goal of developing a comprehensive understanding of plant, animal, and soil microbiomes to produce positive outcomes related to soil health and productivity, food safety and security, forest health, animal health, human health, climate change, and others.

Other - Management of forests and improving forest health requires trained forest health professionals. Ensure that educational and training programs are robust and supported, and notably to include applied tree breeding which serves to harness the genetic variation. Develop public/private networks to engage in participatory breeding and restoration activities.

Other - Biotechnology and genomic approaches may have the potential to mitigate the impacts of biotic and abiotic threats to trees and forests, but decisions about their use must also consider the potential risk or impact of that technology on the environment and on society.

Digital and Automation

Incremental Solutions To Accelerate

- Expansion of satellite-based systems such as ForWarnII with additional high-resolution sensor-based data to inform forest health and presence of stressors.

- Expanded use of LIDAR and Color Infrared (CIR) techniques to produce reliable, high resolution assessments of forest ecosystems.

Transformational Solutions To Create

- Satellites, drones, and ground-based sensors that comprehensively monitor forest health and detect various pests and pathogens, enabling rapid response and control.

- Digital tools coupled with machine learning approaches that enable landscape auto-classification and forest inventory improvements.

Next Era Concepts

- Big data science on forest health issues, from the tree to landscape level, that are spatially explicit and in real-time, with data easily accessed and available to everyone. The system provides high resolution, diagnostic, spatial data informing forest health issues including insects, diseases, plant diversity, and abiotic stressors.

- ‘Tricorder’ type technologies that allow rapid assessment forest health threats and may also allow breeders to much more quickly find rare resistant (to pests, disease, drought, etc.) genotypes to quickly incorporate these into new reforestation and restoration populations.

Gaps, Barriers, and Hurdles

Research – Develop standards for nutrient/water/soil measurements to enable design and implementation of interoperable sensors and decision support tools. Sensors and digital solutions should be scale-neutral, providing solutions for large and small farms and forests, remain accurate and generate high-quality data in a variety of environmental conditions, and be affordable and available to all. Developing sensors and digital ag technologies will require truly trans-disciplinary research among researchers and more trans-disciplinary training of students and workforce, and providing incentives and technical support to enhance uptake and use of these tools by end users.

Prescriptive Intervention

Incremental Solutions To Accelerate

- Decision support tools that identify ecosystem stress indicators and prescribe silvicultural interventions for prevention, mitigation, and control of insects, diseases, and environmental caused mortality.

Transformational Solutions To Create

- Decision support tools that utilize high-resolution digital data informing forest health indicators and recommend rapid interventions that maximize environmental and economic benefits.

- Early pro-active screening to identify forests pests coupled with breeding programs that enable genome design and development of resistance.

Next Era Concepts

- None listed.

Gaps, Barriers, and Hurdles

Research – Develop high-quality data on forest management outcomes for developing conceptual and predictive models that integrate the various components of the forest management system. Integration of data across these studies will require standardized data collection, processing, and analysis. Develop standards for developing interoperable digital tools and products. Collect data from diverse spatial and temporal scales to better model and represent forest-level activities. For instance, collecting and processing soil data, including quantifying soil organic matter, nutrient testing, moisture, and microbial activity across geographies and forest systems will reveal deeper connections between soil measurements, forest production, and environmental outcomes. Artificial intelligence is needed to augment these protocols and reveal previously unknown relationships between various attributes and forest management systems. Up-to-date soil maps are also needed to inform data-based decision making. As the number of sensors in the system increases, consider Swarm Intelligence or Swarm Technology to increase the effectiveness and efficiency of prescriptive interventions.

Research - There is a consistent and chronic threat from invasive exotic pests and pathogens as well as native species starting to become pestiferous, requiring additional research for developing appropriate and effective control methods. Robust integrated pest management strategies including biological control strategies, agents (including beneficial microbials), and developing genetic resistance are needed to protect forests from both native and invasive pests and pathogens. Develop environmentally sensitive methods and decision support tools to eradicate or suppress pest populations, as well as speed the development and delivery of genetic resistance to biotic and abiotic agents.

Research - Expand programs such as ForWarn II, USDA Climate Hubs, HiForm project, etc., to increase the capability of monitoring forest disturbances and recommending interventions that preserve and enhance forest health and productivity.

Research – Develop decision support tools to ingest assessments noted above to create scenario planning systems that can analyze investment tradeoffs and priorities and outcomes. Develop forecasting models to help decisionmakers craft mitigation policies to respond to the growing wildfire threats to people and property and natural resources. These models need to leverage decades of data collection and assessment of risks and threats, and have the capacity to forecast landscape response to management at the appropriate scales.

Other – Develop a national scale forest management financial system to inform the prioritization of forest restoration activities and forecast economic benefits from restoration activities. In this way, the scale and pace of restoration can be amplified by targeting markets and locations where financial incentives can be optimized.

Other – Continue sustained support for USDA Forest Service tree breeding units to help ensure rapid and efficient responses to alleviate long-term impacts of diseases, pests, and climate change. There are currently few such units, and they currently have limited ability to rapidly respond to new threats. The cadre of trained tree breeders is very limited, and succession plans should be developed to help ensure continuity.

Other - Integrated conservation education is needed to make all Americans more aware of the threats of non-native pests and diseases. These threats could greatly impair our ability for the long-term success of proposed programs such as the world-wide Trillion Tree Initiative, and is of high importance to the global community.

Systems-Based Farm Management

Incremental Solutions To Accelerate

- Soil amendments mixed with biochar to increase soil productivity in agroforestry systems.

Transformational Solutions To Create

- Systems-based forest 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, offering better protection of water quality and wildlife habitat, and avoid catastrophic wildfires.

- Forest management practices that promote mixed forest stands in natural forests to increase resilience and adaptation mechanisms to changing environmental conditions.

Next Era Concepts

- None listed.

Gaps, Barriers, and Hurdles

Research - To better manage forest health, new knowledge is required that describes the effects of climate change on interactions between trees, insects, and diseases.

Other - Partnerships between Federal and State agencies and other organizations will be important for achieving shared goals of forest conservation and stewardship. An example is the Joint Forestry Team, comprised of the National Association of State Foresters, National Association of Conservation Districts, USDA Forest Service and USDA Natural Resources Conservation Service. These groups collectively recognize that healthy forests are a critical component of our Nation's landscape providing clean air, carbon sequestration, climate change mitigation, flood protection, wildlife habitat, and recreational and aesthetic enjoyment. The groups work together to deliver forestry-related conservation assistance to private landowners in order to enhance, protect, and conserve America's private working lands. Such partnerships, including others such as university extension specialists, will be essential in enabling forest owners to implement new and innovative tools and practices that increase the health and environmental benefits of forests.

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.

Genome Design

Incremental Solutions To Accelerate

- Develop breeding programs for forest tree species important in agroforestry and urban forests.

Transformational Solutions To Create

- Integrated packages of new tree varieties, or mixtures of tree species, combined with phytobiome organisms that together enable more robust growth, with deeper roots that fix more carbon in the soil and improve soil health indicators.

Next Era Concepts

- Develop new germplasm for improving the health and productivity of forests and rangelands, so that these ecosystems can continue to meet society's needs.

- Full integration of artificial intelligence and machine learning and with advanced genomics and tree breeding to fast-track the development of more productive and resilient forests.

Gaps, Barriers, and Hurdles

Research – Develop a better understanding of tree microbiomes to gain perspective on how microbial communities in and around both the roots and the aerial portion of trees contribute to growth, development, and resilience of trees to abiotic and biotic stresses.

Research - Expand analysis of forest phytobiomes to provide the foundation for developing new approaches to deploy integrated plant + microbiome packages in forestry applications.

Digital and Automation

Incremental Solutions To Accelerate

- Broader use of satellites and other sensors-based systems (e.g., drones and ground-based automated sensors) to obtain more accurate, higher resolution data that inform forest and soil carbon stocks, stream temperatures, water quality and quantity, wildfire smoke pollutants, and soil water content.

Transformational Solutions To Create

- Standards for measuring forest carbon dynamics and low-cost digital tools for monitoring forest carbon content; this information is essential to determine the extent that forests can offset carbon emissions through sequestration, and also enable Ecosystem Service Markets or Carbon Sequestration Markets.

- Standards and digital tools for measuring other ecosystem services such as air quality, water quality, and healthy soils, in both forests and adjacent ag production regions further enabling Ecosystem Service Markets or conservation programs.

Next Era Concepts

- Fully automated system that accounts for carbon content and flux in forests, including above and below ground biomass, with high temporal and spatial resolution.

- Comprehensive suite of low-cost, broadly distributed sensors that measure and quantify other ecosystem services from forests including clean water, air, and soil quality.

Gaps, Barriers, and Hurdles

Research - Develop and promulgate soil health testing protocols, including suites of tests that farmers and foresters can replicate easily and cheaply on cropland, grassland, and forest land to understand, monitor, and track changes in soil health. USDA has done some great work to identify key metrics for measuring healthy soils and protocols for testing, and this work should continue and be expanded to establish a clear set of protocols and standards that are consistent with Agriculture Innovation Agenda (AIA) goals and inform Ecosystem Service Markets and Carbon Sequestration Credit Markets. Harmonize data collections, sample analyses, measurements, and reporting for both public and private entities to aid efforts aimed at environmental improvements.

Research - Improving technologies for measuring forest carbon could significantly increase forest owner participation in forest credit opportunities. Forest inventories and verification are currently costly, and reducing costs for measuring carbon sequestration outcomes would have benefits for forest owners, USDA, and society at large. Soil carbon is difficult to measure, and there is a need for increased investment in reliable and effective measurement/monitoring, reporting and verification technologies, as well as enhancing the COMET model with additional data so that, eventually, farmers and forest owners do not need to independently undertake expensive monitoring to certify credits. Continue to populate the COMET model with more data and sites from across the country to establish credible carbon sequestration rates for all types and locations of forests and soils. Develop protocols to certify carbon credits for sale using COMET to determine sequestration rates, and thus reduce or eliminate the need for expensive monitoring. Support public private partnerships, including interactions between multiple agencies such as the Forest Service, ARS, and NASA.

Research - Develop protocols, standards and long-term monitoring systems to track dynamics and potential impacts of environmental changes.

Other Develop a skilled workforce involved in the forestry sector, including training in the role of markets, forests, and wood products in climate mitigation.

Prescriptive Intervention

Incremental Solutions To Accelerate

- Expand use of AI and machine learning to improve Forest Management Decision Supports Systems, including those used for fire suppression (e.g., Wildfire Decision Support Systems and Wildfire Risk Assessments).

- Develop biotic and abiotic stress resistant forest tree species for use in agroforestry and urban forestry systems.

Transformational Solutions To Create

- Advanced field sensor technologies that monitor soil nutrient cycling, plant-available moisture, and carbon sequestration dynamics, informing forest management decision support systems to realize the full benefits of improved plant genetics and soil microbiome to maximize production capability.

- Expanded implementation of agroforestry practices, including but not limited to windbreaks, shelterbelts, and particularly, stream restoration and enhancement done in proximity to agricultural areas that enhance ag production and increase environmental benefits; measure impacts of the agroforestry to enable Ecosystem Service Markets and Carbon Sequestration Markets.

Next Era Concepts

- 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 AI to uncover and monitor soil health and ecosystem variables to optimize forest production capability and expand ecologically diverse forests.

- Multi-scale early warning network that links machine learning and open data with climate/risk indicators to enable tracking of vulnerabilities in agricultural and forestry regions and the potential for cascading events across landscapes and markets, helping all farmers, foresters and communities to better prepare and mitigate risks.

- Scenario planning tools that leverage big data to provide large scale decision support and prescriptive intervention to guide federal investments in forest and fuel management programs in fire-prone forests.

Gaps, Barriers, and Hurdles

Research - Integrate technological advances with forest management systems to help mitigate climate change impacts and improve forest ecosystems adaptation.

Research - Many agroforestry (and urban forest) practices are not measured or reported as ag or environmental improvements. Through tree plantings and incorporating agroforestry practices into their operations, producers can diversify their production system and sources of revenue, enhance ag production, and sequester carbon while providing numerous environmental benefits including clean air, enhanced water quality and quantity, and improved wildlife habitat and biodiversity, including pollinators. Quantify and analyze these benefits to determine which practices have the greatest environmental and economic impact, and establish quantifiable metrics that enable ecosystem markets to help incentivize their adoption. Increased collaboration between groups such as the state forestry agencies, The National Agroforestry Center, The Joint Forestry Team, University, and the USDA Forest Service Forest Inventory and Analysis program is needed to strengthen, streamline and use data collection efforts to establish a baseline inventory from which future agroforestry improvement and benefits can be measured. Strengthen cooperation between these groups to help support coordinated interagency delivery of forestry-related conservation assistance to private landowners to enhance, protect, and conserve America's private working lands.

Research - Integration of biotic and abiotic stress resistance into forest tree species used in agroforestry practices, and urban forestry. For example, ash is an important species in riparian buffer zones, windbreaks, and shelterbelts, especially in the Great Plains States, where ash (facing extinction due to EAB) is one of only a few species that can withstand the harsh environment.

Research - Develop and integrate systems to bind data collection and assessment with decision making tools. New decision support systems are needed to respond to emerging forest threats catalyzed by changing climate and land use practices. Develop forecasting models that incorporate uncertainty associated with natural disturbances, especially wildfire, to provide risk-based decision support tools.

Research - Refine climate change models and interpretations to provide better guidance on tree species and genotype choices that will meet short, mid, and long-term society needs of healthy forests and the accompanying benefits.

Other - A greater understanding of the needs of urban forests to benefit both human health and the help mitigate impacts of a changing climate, and what technological advances are needed to provide more optimal urban forests across the United States.

Systems Based Farm Management

Incremental Solutions To Accelerate

- Develop and test silvicultural systems and forest management techniques that consider dynamics of forest vegetation changes associated with climate change.

Transformational Solutions To Create

- Thoroughly investigated, incentivized forestry management practices and recommendations that have clear linkages to forest products innovation, increased carbon sequestration, Ecosystem Service Markets and/or Carbon Sequestration markets.

Next Era Concepts

- Comprehensive forest modeling system that recommends best management practices that increase carbon sequestration, water quality protection, and other ecosystems services that are measured and quantified, enabling Ecosystem Service Markets and Carbon Sequestration Markets.

Gaps, Barriers, and Hurdles

Research - Develop the use of new technologies and applications to expand support for the Forestry Inventory, Analysis and Monitoring (FIA) program, or similar programs, to enable higher resolution data needed to quantify the benefits of forestry and determine best practices and management approaches for maximizing environmental and economic benefits.

Research - Systems analysis tools and software are needed for monitoring and assessing forest carbon flux, and quantifying the benefits of specific forest management practices to enable Ecosystem Services Market or Carbon Sequestration Markets. Such methods may include remote sensing and drone-based forest inventory technologies and modeling.

FORESTRY – MARKET EXPANSION AND DIVERSITY

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

Genome Design

Incremental Solutions To Accelerate

- Tree species improved for diversified end-use markets (e.g., building materials, biofuels, bioproducts, etc.).

Transformational Solutions To Create

- Trees with high-value end-use traits (e.g., building materials, biofuels, bioproducts, etc.).
- Enzymes and microorganisms with enhanced efficiency for production of biofuels and/or bioproducts from forest-related residues.
- Molecular tools such as metabarcoding that can be used to rapidly identify potentially invasive species that contaminate transported or trade-derived products.

Next Era Concepts

- None listed.

Gaps, Barriers, and Hurdles

Research - Expand the use of forest-based feedstocks for producing biofuels and bioproducts, including cellulosic ethanol, bio-jet fuels, and optimized for biodiesel production, biogas, bio-oils, and other post-harvest treatments such as enzymatic treatment, thermotropic conversion, and cracking and reforming to produce higher value chemical feedstocks.

Digital and Automation

Incremental Solutions To Accelerate

- None listed.

Transformational Solutions To Create

- Sensors and diagnostic tools for pest identification and detection during transport and at first introduction; e.g., diagnostic sensors placed in shipping containers or in nurseries.

Next Era Concepts

- Use of standard databases for machine learning and highly automated computational processes for natural resource management and conservation.
- Standard monitoring mechanisms that measure the impacts of harvesting on biodiversity, soil erosion, and water quality of streams through the production chain.

Gaps, Barriers, and Hurdles

Research – Develop low-cost, easily deployed sensors and technologies that can detect and diagnose specific pathogens and diseases during import, export, and distribution networks.

Research - Develop standards for natural resources databases and their application in different applications of Decision Support Systems for risk assessments, resource planning assessments, trends and future scenarios, forest management, wildfire suppression, ecosystem services assessments, etc.

Prescriptive Intervention

Incremental Solutions To Accelerate

- Expanded opportunities for start-ups and new technologies to open new markets for wood innovations.

Transformational Solutions To Create

- Decision support tools that enable detection and recommend treatments of pests or pathogens associated with trade.
- National financial assessment models that forecast forest product supply chain under alternative investment strategies in forest restoration.

Next Era Concepts

- Comprehensive global monitoring system that enables detection and treatment of pathogens and diseases that have potential impacts on forests.
- Comprehensive global monitoring system that enables detection and identification of illegal plant and wildlife species trade that enables fair trade and market development.
- Financially viable forest restoration in fire prone ecosystems.

Gaps, Barriers, and Hurdles

Research - Trade and transport have been identified as major routes for introduction of non-native pests and pathogens. Need predictive models that integrate complex, context-dependent phenomena governing these processes, and develop integrated measures that should be applied in nurseries or transport to minimize the risk that pathogens are present. This should be complemented by research to identify effective means for regulators to determine whether the integrated measures have been carried out and are successful in preventing pathogen presence.

Research - Develop and apply a national scale financial modelling system to forecast wood product markets derived from forest health and restoration management under predicted climate change scenarios.

Systems-Based Farm Management

Incremental Solutions To Accelerate

- Expanded portfolio of diversified end-use products for wood, non-wood forest products, and carbon-based feedstocks that stimulate forest production and active forest management.

Transformational Solutions To Create

- Systems analysis tools that 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.

Next Era Concepts

- Robust, diverse marketing opportunities for wood-based products that drive forest production and management systems that increase carbon fixation, increase environmental and societal benefits, and maximize economic returns.

Gaps, Barriers, and Hurdles

Research - Trees absorb carbon dioxide from the air, convert it to wood, and release oxygen in the process. It is estimated that about 11percent of the Nation's carbon emissions are offset by the additional carbon stored in U.S. forests and wood products each year. Programs that increase the extent of forests and tree growth and promote greater use of wood products (e.g., the USDA's Forest Products Research Lab, the Wood Education and Research Center, Wood Innovation Grants, and the mass Timber University Grant Program, etc.) ultimately lead to increased carbon storage. Though forests can provide other forms of economic return, such as from recreation, appreciated land values and ecosystem services, harvesting trees for wood products is the predominate source of revenue for forest owners. It is important to expand the diversified end-uses for wood-based products. Promising, emerging wood-based products and markets include subsidized power production in Europe, where government policy is focused on eliminating coal-fired operations over time; new building materials that effectively sequester carbon and often generate a smaller carbon footprint during manufacture and use; biofuels that help reduce dependence on fossil fuels while meeting transportation needs, particularly in sectors such as aviation or heavy machinery that are not as amenable to electrification; biochar, which is a by-product of pyrolysis-generated biofuels, to serve as a soil amendment that lowers acidity, binds undesirable metals, increases soil porosity in tight clays or reduces porosity in soils that drain too quickly, and creates a favorable environment for soil microbes; biochar also has potential as a cattle feed additive to reduce enteric methane emissions and increase animal productivity; production of wood-based fuel pellets through torrefaction; cellulosic biofuels; mass timber for building materials such as cross-laminated timber, which is produced in large panels that rival steel in strength and fire resistance, while stronger than concrete; and cellulosic nanotechnologies such as nanocrystals and nanofibrils that are lightweight, strong, stable and stiff, serving as additives for paint, coatings, adhesives, cement additives, and composites that replace plastics.

Research - It is important to co-develop new wood-based marketing opportunities with science-based management strategies that maximize economic and environmental benefits and incentivize best practice adoption. Wood should be harvested in a carefully planned manner using best management practices that embody sound science, represent community values, continue to provide important environmental benefits, and reflect responsible economics. Life cycle analysis research is needed to better understand how wood-based products impact the climate and produce other environmental benefits. Education and technical support for foresters is needed to incentivize adoption and implementation of best practices. Government and universities play an important role; e.g., expanded forest products technical assistance within the university extension system through e.g., USDA National Institute of Food and Agriculture grants available under the Renewable Resources Extension Act Program.

Other - Increased demand for wood incentivizes investment in forests and their active management. For instance, Colorado's forests have a low baseline productivity rate compared to other States for several reasons, including a low baseline rate because of the State's dry climate. Fire suppression, insects, disease and drought over the last 100 years have led to overly dense forests in which trees are dying faster than new trees are establishing, meaning Colorado's forests are a net source of carbon emissions based on 2020 estimates from the USDA Forest Service. Greater development of the forest products industry could help sequester carbon in wood products while removing dead trees, thinning overstocked forests, reducing wildfire risk for communities and enhancing forest health.

Other - Increasing the use of wood and wood-based products requires education of end users such as architects, designers, and engineers in the construction and infrastructure sectors to better understand the benefits of using wood-based materials. Need significantly more support for tech transfer and market research/demonstration opportunities that focus more on processes and capacities to scale adoption and technology transfer of wood and wood innovation use, such as how to create replicable building and infrastructure specifications for using wood, advance relevant building codes for taller wood buildings, and how to deliver these resources to key users such as designers, engineers, and architects.

BEEF AND RANGE – PRODUCTION

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

Genome Design

Incremental Solutions To Accelerate

- Cattle selection tools that benefit cow-calf producers and enable rapid use of advanced genetics (e.g., the iGENDEC web-based sire selection tool).

Transformational Solutions To Create

- Cattle with low enteric methane emissions and high feed efficiency.
- Cattle with strong immune systems that reduce the need for antibiotics and have high resistance to infections/diseases, including endemic diseases such as bovine respiratory disease.
- Healthier animals that require fewer calories with low mortality and high growth rates.

Next Era Concepts

- Co-breeding of crops and animals to deliver optimal feed and animal genetics that maximize nutrient use efficiency, while minimizing enteric methane emissions.
- Designed microbiome that increases nutrient use efficiency and improves animal health, with reduced enteric methane production.

Gaps, Barriers, and Hurdles

Research - Improvements in precision genetics (i.e., gene editing) are needed to increase outputs of protein per animal unit to allow a decrease in animal numbers to produce equivalent amounts of high-quality food.

Research – More information is needed regarding the genomic and environmental factors affecting the rumen microbiome, particularly in relation to animal health, nutrient use, and enteric emissions. New microbiome ecology concepts are needed to inform strategies to manipulate microbiomes (e.g., microbial interactions, enzymatic interactions).

Research - There is a significant challenge to integrate “omics” datasets (genomics, proteomics, metabolomics, and transcriptomics) with high-throughput phenotyping and artificial intelligence to uncover important quantitative trait polymorphisms that can be used to improve genomic prediction. Develop assays that accelerate phenotyping, and strategies that reduce genotyping costs (e.g., imputing genotypes to the genome sequence level using low cost, low coverage genotyping). Accelerate genetic improvement in sustainability traits (such as fertility, improved feed efficiency, welfare, and disease resistance) using big genotypic and sequence datasets linked to field phenotypes and combined with genomics, advanced reproductive technologies, and precision breeding techniques to enable a 10-fold increase in genetic improvement. Multidisciplinary programs between veterinarians, microbiologists, animal nutritionists, and breeders are needed.

Regulatory – Reduce in regulatory hurdles to allow for a risk-based approach that takes into consideration the familiarity or complexity of the genetic changes. Need to harmonize the regulation of genome editing in food species, especially for plants and animals that could otherwise have been developed through traditional breeding techniques. Having a much higher and disparate regulatory barrier for genome edits in the animal kingdom is not scientifically justifiable from a risk perspective, and needlessly disadvantages both U.S.-based animal genetic researchers, and more generally American animal agriculture. USDA-APHIS is the appropriate agency to oversee genome editing in plants and animals for agricultural purposes. FDA's proposed approach to regulate intentional genome alterations in food animals as drugs is a regulatory hurdle that will disadvantage uniquely both U.S. researchers and animal agriculture.

Digital and Automation

Incremental Solutions To Accelerate

- GPS monitoring of animals combined with management strategies that improve the uniformity/completeness of rangeland/pasture use.
- Pasture/Rangeland methods that accurately assess feed intake.
- Hyperspectral analyses that identify forage plants within the range/pasture setting.
- Virtual fencing applications.
- Utility of organic compound detection for monitoring metabolism and disease.

Transformational Solutions To Create

- Sensors that monitor nutrients, herd health, microbial/gut health, forage and feed quality, and behavioral indicators of health.
- Sensors that inform physiological status of individual animals; e.g., biosensors such as color-changing biotattoos that detect an increase in lactate in dairy cattle (an indicator of developing low milk yield) or cortisol in cattle (an indicator of stress).
- Strategies that integrate forage plant identification, automated intake methods and virtual fencing to optimize individual animal nutrient intake and range/pasture utilization.

Next Era Concepts

- Low-cost, easy-to-use and broadly dispersed diagnostic sensors that provide real-time, animal specific data that inform animal health, stress levels, and presence of pathogens or disease.

Gaps, Barriers, and Hurdles

Research - A range of sensors and data flows are needed to capture data and create information on behavior and well-being of animals to improve management of livestock. Sensors must be robust, able to function in a range of challenging environments and provide data at costs that make them viable. Many novel technologies are too expensive for commercial livestock producers and lack a user-friendly interface to facilitate their adoption. Incentives for adoption, technical support, and education are needed. The University extension systems play a key role here.

Research - Standards are needed to enable design and implementation of interoperable sensors and decision support tools. Sensors and digital solutions should be scale-neutral, affordable and available to all farmers. Developing sensors and digital ag technologies will require truly trans-disciplinary research among researchers and more trans-disciplinary training of students and the associated workforce.

Research - Additional research is needed for developing biosensors that monitor individual animal health and performance. For instance, biotattoos sample various bodily fluids such as sweat, saliva, or tears and inform physiological status and animal well-being. Information can be transferred via cell phone to create a timestamp as well as geographic coordinates that could be used for more effective local, regional, and national coordination of overall stress or developing disease (NAS, 2019).

Prescriptive Intervention

Incremental Solutions To Accelerate

- Feed rations that are more precisely formulated to maximize use efficiency and minimize negative environmental impact, and technologies that can more precisely deliver feed to animals on an individualized basis.

Transformational Solutions To Create

- Feed formulations that maximize nutrient use efficiencies and leverage microbiome activities.

- Suite of feed additives that improve animal health, nutrient efficiency, and performance (e.g., chemicals that control coccidiosis and other bacteria, reduce rumen acidosis and bloat in feedlots, and reduce pulmonary emphysema due to lush pasture conditions; microbiome amendments that enable increased nutrient use efficiency with reduced enteric methane production; enzymes that aid in animal digestion and nutrition; and alternatives to antibiotics such as immunomodulators, bactericidal agents, nutraceuticals, and probiotics).

- Decision support tools coupled with diagnostic sensors that detect animal diseases at the earliest moment, even before clinical signs are obvious, enabling early prescriptive interventions.

- Improved animal vaccines, including those produced by traditional or non-traditional approaches.

Next Era Concepts

- Prescriptive livestock farming (PLF) systems that enable individual-animal-targeted nutrition, health, and welfare (NAS, 2019).

Gaps, Barriers, and Hurdles

Research - The objective of prescriptive livestock management is to create a management system based on continuous automatic real-time monitoring and control of production/reproduction, animal health and welfare, and the environmental impact of livestock production. Monitoring can be done remotely through sounds, sights, animal movements, and estimations of environmental parameters such as temperature, humidity, or air particulates. Investigation of specific sounds using continuous monitoring systems such as AI to uncover patterns that inform optimal growth, well-being or signs of stress, such as early coughs experienced in bovine respiratory disease and/or maternal well-being. The biggest obstacle for precision livestock farming is the data science challenge of transforming multiple types of data from various sensors and sources into knowledge. This knowledge could then be used to accurately predict a genetically superior animal, an animal in distress or presenting disease symptoms, or an abnormal state that requires farmer intervention. Developing farmer-friendly, cost-effective plug-n-play precision livestock farming applications will require collaboration among animal scientists, agricultural engineers, and data scientists focused on a shared vision of animal-centered care. There is insufficient focus in current funding calls on bringing together the disparate disciplines needed to address complex problems using data science. (NAS, 2019).

Research - It will be important to develop strategies to decrease the use of antibiotics in food animals without negatively impacting productivity, animal health, or animal welfare. Developing alternatives to antibiotics is dependent, in part, on basic research that better defines the processes important to pathogenesis, thereby enabling development of more targeted interventions and solutions. Identify and avoid subclinical, inflammatory mechanisms in livestock to enable producers to avoid losses by melding immunology, endocrinology, and metabolism to improve health and well-being of livestock. Enable better disease detection and management using a data-driven approach through the development and use of sensing technologies and predictive algorithms. Sensors and the data they provide combined with data science holds great potential to improve understanding of population dynamics in animals and improve their well-being and productivity.

Regulatory - Collaboration across Federal agencies to facilitate the adoption of technologies that fall under the regulations of different agencies is vital. For example, many feed additives that reduce enteric emissions are regulated by the Food and Drug Administration. The industry is very interested in this technology and the impact it can have on reducing enteric emissions, but the industry cannot adopt the technology unless approved by the FDA. Through interagency collaboration involving FDA and other agencies, viable ag technologies can proceed through the regulatory process in a timely manner.

Systems-Based Farm Management

Incremental Solutions To Accelerate

- None listed.

Transformational Solutions To Create

- Animal facilities and environments designed to minimize stress and maximize animal well-being and productivity.

- Systems-analysis tools that 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.

Next Era Concepts

- Integrated data generation and decision-making tools that combine monitoring and data analysis.

Gaps, Barriers, and Hurdles

Research - Looking at the full ag supply chain through the lens of multiple sustainability indicators will reveal new opportunities for improvement and identify tradeoffs. Industry efforts will have little impact, however, without increased consumer awareness and communication. Consumers need to be educated about the dynamic nature of ag production, and that tradeoffs often occur as new approaches and tools are implemented. For example, a decision impacting ag air emissions might have tradeoffs with water use impacts.

Research - Objective, scientific standards for animal welfare need to be developed and applied that allow for quantifying animal health and impacts of various management practices. Need to determine how those standards can be incorporated into precision livestock systems, and how the social sciences can inform and translate scientific findings to promote consumers' understanding of trade-offs and enable them to make informed decisions (NAS, 2019). Further, with increasing efficiencies and intensity of production, animals need to be reared in systems that promote animal welfare, minimize GHG emissions and pollution, and decrease the potential for foodborne illness. Development of reliable biomarkers will be helpful in informing what types of housing facilities and environments are best suited for animals. Design professionals could combine this information with their understanding of efficiency of operations, disinfection procedures, and worker safety and health to improve animal facility design that integrates sensors and electronic monitoring and improving animal health and well-being. As an example, sensors in animal rooms could be tied to the air handling and lighting systems to ensure optimal temperature, humidity and ambient light; visual and/or audio analysis of behavioral cues that inform expression of innate behaviors could signal appropriate interventions, such as activating access to an outdoor yard so that animals can be fulfilled.

Other - Despite evidence of being a sustainable supply system, the beef industry is currently fighting negative sustainability perceptions. Need to educate the public and promote a positive image of sustainability. USDA is the public representative of U.S. ag production and should continue to be actively involved in promoting a positive environmental message both domestically and abroad.

Other - To drive adoption and implementation of innovative tools and practices, it will be essential to support education, communications, networking and outreach that fosters the dissemination of major innovations at scale. Incentives that promote adoption and minimize financial risk are also needed.

BEEF AND RANGE – PRODUCTION CAPABILITY

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

Genome Design

Incremental Solutions To Accelerate

- Genomic selection for drought tolerance and other characteristics for grasses and legumes.

Transformational Solutions To Create

- Forages as cover crops with improved nutrient content and digestibility for animals, leaving plant residues on the ground, keeping soil moist, protecting against evaporation, and reducing erosion.

- Perennial grass stands as forages that serve as carbon sinks, with improved fiber digestibility and reduced enteric methane emissions.

- Increased livestock production efficiency by raising the feed crop yield per acre (e.g., improved drought tolerance or nitrogen-use efficiency in corn).

Next Era Concepts

- Soil microbiome that enhances capture and availability of nutrients to increase feed production efficiency and reduce losses to the environment.

- Genome design to increase plant capability to convert CO_2 to carbohydrate under higher CO_2 conditions.

- Nitrogen fixation in corn and other crops used for livestock feed.

Gaps, Barriers, and Hurdles

Research - Expand research on usage of rangelands for animal production through active rangeland management. Rangelands represent 30 percent of the land area of the United States and contribute both directly and indirectly to U.S. ag production and production capability. Ranges include natural grasslands, savannas, many wetlands, some deserts, and certain forb and shrub communities. Rangelands offer native land plants that serve as forage for grazing animals including cattle, sheep, goat, and horses. Through their extensive root systems, rangelands can store and sequester carbon at rates that exceed or match that or forests. Their inherent plant diversity provides ecosystem and watershed protection by increasing soil organic matter, moderating precipitation runoff, and reducing soil erosion. Ranges have multiple uses, including used as a source of forage, timber, minerals, natural beauty, and recreational opportunities, and must be managed in a manner that balances benefits for landowners and the general public. Rangelands provide a major source of forage for livestock production, quality sources of water through healthy watersheds, important fish and wildlife habitat, and active sinks for atmospheric carbon to counter global warming trends.

Research - Develop forage, feed, and cover crops within the context of advanced soil health management practices such as regenerative, conservation agriculture and other agroecological cropping systems to maximize soil and environmental benefits using crop genetics.

Digital and Automation

Incremental Solutions To Accelerate

- Precision application of fertilizers and water to pastures using remote sensing.

Transformational Solutions To Create

- Sensors that monitor forage quality and yield and quickly identify issues in the field to enable management or adjust the timing of harvest/grazing.

- Sensors and digital tools that measure range and pasture health indicators (e.g., carbon sequestration, water quality, air quality and GHG emissions, biodiversity, biotic integrity, soil/site stability, hydrological function, etc.) to inform the impact of various management strategies and enable Ecosystems Services Markets and Carbon Sequestration Markets.

Next Era Concepts

- Remote sensing of soil and water nutrient levels using hyperspectral or quantum detection.

Gaps, Barriers, and Hurdles

Research - Define rangeland health indicators and develop standards and sensors for their measurement. Develop tools for identifying and managing major rangeland issues including invasive species, wildfire, drought, etc.

Research - Develop and promulgate soil health testing protocols, including suites of tests that farmers can replicate easily and cheaply on cropland, grassland, and forest land to understand, monitor, and track changes in soil health. Need to harmonize data collection, sample analysis, measurement and reporting for both the public and private entities to aid efforts aimed at measuring the environmental impacts of various management practices and enabling Ecosystem Service Markets and Carbon Sequestration Credit markets.

Research - Develop a better understanding of water-quality implications of advanced practices and technologies, and support the calibration and validation of existing water-quality models.

Regulatory - Expand and advance the use of Cooperative Monitoring Agreements and the Ecological Site Description system to improve data collection efficiency and useful monitoring metrics between agencies such as USDA Forest Service, USDA Natural Resources Conservation Service, and landowners, local agencies such as conservation districts and counties, and community-based organizations and rangeland management specialists. When considering greenhouse gas (GHG) production, the Environmental Protection Agency (EPA) is encouraged to use the updated Global Warming Potential methodology (GWP), which takes into consideration the lifetime of different gases in the environment.

Prescriptive Intervention

Incremental Solutions To Accelerate

- Define "soil health indicators," especially those relevant to enabling Ecosystem Service Markets or Carbon Credit Markets, and establish standards for their quantification and reporting.

- Increase adoption of practices like perennials and cover crops that improve soil functions to increase yield, nutrient use efficiency, and water management.

Transformational Solutions To Create

- Decision support tools that enable advanced grazing to manage forage loads and rangeland health; e.g., coupling virtual fence controls based on wireless technologies and electric collars with sensors that inform forage quality and quantity, thereby controlling animal movements to improving rotation efficiency and environmental benefits, and steering cattle away from certain waterways, thereby improving water quality.

- Sensors, drones or other scouting methods and tools that detect invasive annual grasses such as cheatgrass (with limited forage value) and other pests coupled with a suite of prescriptive interventions, including management practices, that mitigate these pests, improve wildlife habitat, increase livestock production, and reduce risk and extent of wildfires across the range.

- Expanded usage of agroforestry or silvopasture practices that increase environmental and economic benefits.

- Decision support tools and technologies that reduce odor, ammonia, nitrous oxide, hydrogen sulfide, methane, and non-methane gasses from cattle and manure for reduced emissions and improved quality of life in rural communities.

Next Era Concepts

- Use of soil microbial interventions that can reduce weed stress on crops and increase nutrient use and efficiency.

Gaps, Barriers, and Hurdles

Research - Additional research is needed on the benefits of ruminants in ecosystems, and how to optimize the use of grazing as a tool to manage rangelands and other forage systems. Land-Grant Universities and Extension will also be essential partners in conducting research and promoting solutions to issues such as treating invasive annual grasses that affect productivity and increase rangeland wildfires. With improvements in sensor technology, machine learning and IA, there will be an increase in productivity of livestock systems through enhanced nutritional/pasture management, disease control and surveillance and enhanced opportunities for regenerative practices in agriculture. Rangeland management techniques including adjustments in stocking rates and managing invasive shrubs and trees present numerous carbon sequestration opportunities. A comprehensive herd management plan includes prescribed grazing, monitoring of livestock and land health, rekindling of the herd instinct, and husbandry practices implemented through progressive stockmanship techniques (e.g., low stress livestock handling).

Research - Need innovation in proactive, nonlethal human-wildlife conflict reduction practices such as improved herd management through progressive stockmanship, electric fencing, and carcass management. Carcass removal is important to reduce attractants that may draw carnivores into areas with livestock. Electric fences can be an effective nonlethal technique, but additional research is needed to optimize this technology for effectiveness to large carnivores such as grizzly bears and wolves.

Research - Research is needed on the impacts of agroforestry and silvopasture practices on environmental and economic benefits of ag farming system. Agroforestry practices such as windbreaks and shelterbelts utilize linear planting of trees to provide economic and environmental benefits for ag producers by mitigating the effects of winds while improving conditions for soils, crops, livestock, wildlife, and communities. Windbreaks help protect crops from damaging winds, prevent soil erosion, increase crop yields, and pollinator habitat, and provide relief for livestock from harsh weather conditions that can affect animal productivity due to increased stress and mortality rates. Riparian forests allow precipitation to be absorbed and released slowly into rivers and streams over time, reducing erratic flows that contribute to down-stream flooding. During flood events, buffers reduce the velocity of water, allowing more water to infiltrate into the soil and recharge ground water. Stream restoration provides additional benefits including enhancing water quality, filtering and absorbing pesticides, bacteria, and sediments and curbing other pollution such as nitrate stemming from ag production. Through tree plantings and incorporating agroforestry practices into their operations, ag producers can diversify their production system and sources of revenue, enhance ag production, and sequester carbon while providing numerous environmental benefits including clean air, enhanced water quality and quantity, and improved wildlife habitat and biodiversity, including pollinators. Coordinated reporting and monitoring of tree inventories on ag lands and other practices is needed, including measurement of their economic and environmental impacts.

Systems-Based Farm Management

Incremental Solutions To Accelerate

- Broader implementation of technology and new management paradigms that improve efficacy of rangelands management, including tools such as portable electric fencing and visual cues for minimizing animal interaction with fences, solar fence charge and solar water pumps, remote sensing drones, virtual fencing with global positioning system (GPS)-enabled collars, automatic gate latches, and grazing management and monitoring apps compatible with smartphones and tablets.

Transformational Solutions To Create

- Systems design tools that consider incorporation of agroforestry, silvopasture, advanced grazing management, or other production practices that increase environmental benefits, and quantifying these benefits to enable Ecosystem Service Markets or Carbon Sequestration markets.

- Incentivized on-farm production of energy (e.g., agrivoltaics, biogas, wind farms) that reduces net carbon emissions and farm waste while maximizing production and environmental benefit; e.g., integrate livestock into solar fields.

Next Era Concepts

- Systems-based farm management that considers economic and environmental benefits across the ag production chain including production of animal feed, herd health, advanced grazing management, manure management, marketing, and societal impacts and recommends best practices that improve livestock health and production with increases in environmental, economic, and societal benefits.

Gaps, Barriers, and Hurdles

Research - Determine the climate impacts of various livestock production systems; for instance, does grain-based ruminant production have a lower carbon footprint (due to faster growth and lower enteric methane emissions) or grass-based production (with greater potential for soil carbon sequestration). Improved life-cycle analyses of livestock production systems are also needed to accurately quantify climate impacts of concentrated animal feeding operation (CAFO) based and pasture-based production systems. Need more reliable data on carbon flux and content in rangelands and grasslands to inform policy recommendations and understand effects of different grazing and land management practices on the ability of rangelands and grasslands to sequester carbon.

Research - Maximize the ability of pasture and range to support livestock diets to provide an alternative to traditional feed, freeing up arable land for other food or utilizing land that is not otherwise suited for crop production. Develop Management Intensive Grazing (MIG) and other advanced grazing management systems adapted to various locales that restore soil and forage health, improve livestock health and production, and sequester additional carbon annually; differences in livestock management require research conducted in those different regions to address unique systems and challenges. Obtain higher quality data and metrics that inform how grazing lands are managed.

Regulatory - The Conservation Reserve Program (CRP) has been very successful in dramatically lowering the environmental footprint of row crops through creation of millions of acres of grassland that are not used for either crop or livestock production. There are opportunities to consider returning CRP lands, or shifting marginal crop lands, into sustainable livestock production systems that employ perennial grasses and actively managed grazing systems to increase economic and environmental benefits.

Regulatory - The entire ag industry broadly supports the development of a free-market system that will compensate farmers, foresters, ranchers, and producers for the environmental benefit they create. USDA is urged to support these markets, but refrain from engaging too heavily to ensure the markets' free-market nature. Industries are concerned about regulatory policies that put mandates on utilization of production practices that have environmental benefits, such as GHG reductions; it is believed that a more effective approach is a voluntary, incentivized system that rewards producers for adopting such practices. The latter system is also more conducive to innovations that further improve environmental impacts. Support is needed for programs that support ecosystem service markets, ranching systems, and other forms of land management that increase soil organic matter, carbon content, aggregate stability, and water retention to improve overall health and profitability of rangelands. Identify and secure programs that recognize ecosystem services provided by well managed rangelands and reward those who strive to maintain healthy soil, water quality, secure carbon, and wildlife habitat while managing productive ranching enterprises. Further, ensure livestock production on rangelands remains economically viable through, for example, funding for risk management for conservation innovations or other mechanisms for individual ranchers who lack financial flexibility to undertake new practices that enhance rangeland conditions and, thereby, the productivity of their operations.

Regulatory - The ag industry is vital to many rural economies, but there is a lack of coordination between Federal agencies and State and local plans for managing and utilizing rangelands. This makes it very difficult to implement sound management actions with respect to fire suppression, fuels reduction, recreational opportunity, livestock management firewood cutting, mineral and energy exploration and the many other activities that are clearly in the local, State, and national interest. Need better coordination and discussion between various agencies in USDA (primarily Forest Service) with local ag producers and local communities in policy development. A greater emphasis on systems level thinking and landscape level planning is needed to enhance the stability of food production while providing for more prosperous rural livelihoods and enhancing biodiversity conservation.

Other - In addition to developing innovative tools and practices, it is important to prioritize and support innovative management paradigms, information sharing, knowledge creation, peer- o-peer innovation sharing, and producer trainings. Need to change how American farmers and ranchers think through management challenges; adopting new technologies and tools may help farmers and ranchers incrementally increase production or reduce environmental damage, but they need access to the understanding behind the new practices and gadgets for lasting and resilient outcome improvements to be achieved. Support and encourage workshops helped by NRCS and State Extension as well as private-sector organizations like Ranching for Profit, Holistic Management International, publications like On Pasture and the Stockman Grass Farmer, and podcast such as Working Cow Podcast and The Art of Range, with financial support for producers to attend workshops or other incentives. Expand extension and technical assistance for climate-friendly and carbon-sequestering practices, for example by expanding and strengthening the USDA Climate Hubs, establishing regional agroforestry centers, and expanding funding to Extension. Expand outreach efforts that embrace social considerations, including racial equity, establishing the next generation of farmers, human health outcomes (optimizing nutritional value per acre) and integration of urban and nearby rural communities.

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.

Genome Design

Incremental Solutions To Accelerate

- Genomic breeding values for specific regions of the country tailored to key sections of the beef production chain.
- Use of gene drive technologies to eliminate disease-carrying insects.

Transformational Solutions To Create

- Cattle that are more resistant to heat, leading to increased production in impacted regions or expanding into new geographic production areas.
- Additional sources of animal-derived proteins, such as cell-based protein products.
- Genomic solutions to tick and biting insect resistance, which would help suppress disease transmission carried by ticks and other insects, particularly in the South.

Next Era Concepts

- Public acceptance of gene-edited cattle would vastly increase opportunities for genome design in cattle, including marketing opportunities.

Gaps, Barriers, and Hurdles

Research - As global demand for protein increases, expand the design and production of cell-based protein products that complement animal proteins and meet consumer demand. Molecular engineering processes for developing alternative sources of protein need to get faster to accelerate the speed of innovation and must be amenable to scale up. Identify and engineer microbes to aid in production of protein products, either directly or indirectly through production of growth factors, which are currently among the primary cost drivers for cultivated meat production. Identify appropriate cell lines for development for cultivated meat products, including cow, pig, chicken, or salmon and select or engineer for properties such as high-efficiency differentiation, enhanced proliferative capacity, and tolerance for high-density cultivation.

Research - Expanded analysis of environmental factors and disease prevalence for the 10 most destructive diseases in the cattle industry.

Digital and Automation

Incremental Solutions To Accelerate

- Sophisticated models linking disease prevalence, insect vectors and environmental factors (e.g., VSV Grand Challenge) to help with bio-surveillance, disease outbreak early warning, and vaccination strategies.

Transformational Solutions To Create

- Blockchain or similar technology that enables traceability throughout the food production system.

- Sensors that detect and inform the presence of pathogens and diseases, including zoonotic diseases, across the supply chain, from animals to animal-based products.

- Digital technologies and automated processes that address labor shortages and safety.

Next Era Concepts

- Comprehensive monitoring system that tracks animal health, well-being, and presence of pathogens integrated with a global surveillance system to detect emerging biological threats, track their global movements, and anticipate mitigation strategies to minimize losses and increase public safety and economic prosperity.

Gaps, Barriers, and Hurdles

Research - Additional research is needed to expand the development and implementation of national and international disease tracking systems, such as the National Bio- and Agro-Defense Facility (NBAF) and the Global Surveillance System (GSS), to detect and block transboundary animal diseases such as avian influenza or foot and mouth disease. Digital technologies should align with One Health Initiatives and strengthen capacities for surveillance of zoonotic infections and bolster the ability of existing State and Federal laboratory networks ability to rapidly detect, report, and respond to new emerging biological threats.

Research - As labor availability continues to be a primary concern across multiple segments and geographies in the ag supply chain, the promise of digital technology and automation holds promise for many area of production and processing.

Prescriptive Intervention

Incremental Solutions To Accelerate

- None listed.

Transformational Solutions To Create

- Diversified opportunities for using animal waste such as urine, feces, bedding material, and wash water as feedstock for value-added products such as fertilizers or energy production.

- Identify areas along the food production chain where rapid changes and interventions can be implemented to re-route or re-distribute food rapidly when market accessibility changes.

Next Era Concepts

- On-farm manure processing and use technologies that extract nutrients for recycling as fertilizers and use carbon for energy generation and carbon sequestration.

Gaps, Barriers, and Hurdles

Research - Develop new value-added uses for manure, such as manure-based products or feedstocks for bioenergy (e.g., clean energy production from anaerobic digestors, renewable fertilizers from manure that also improve soil health and long-term carbon capture, etc.). As an example, manure processing using thermal evaporative technology to produce dry solids containing all nutrients except ammonia nitrogen, aqua ammonia, and recyclable water. The dry solids and aqua ammonia show promise to meet organic fertilizer certification requirements. These new manure-based products can be used on and off farm, displacing commercial fertilizers, providing new sources of off-farm revenue, and allowing the farm system to operate in a more circular, sustainable manner. Further, external waste streams might be incorporated into on-farm digesters to increase renewable energy production and receive additional greenhouse gas (GHG) credits from waste that would otherwise be sent to the landfill or land applied. Evaluate technologies that produce renewable energy from waste streams with the goal of developing recommendations on the use of financial incentives to achieve maximum environmental benefit.

Research - Practices and technologies exist today for farmers to lower their carbon footprint and improve water quality but require further development, significant on-farm operational changes, investment and advanced technical assistance that limit widespread farmer adoption. Need technologies that not only accelerate improvements, but enable nimble adaptation and focus on technologies that can be scaled for maximum impact.

Research - Livestock producers can significantly reduce greenhouse gas emissions through methane digesters, methane capture, new feed combinations that reduce enteric emissions, improved grazing systems, and other advances in manure management, but significant research is needed to advance and optimize these systems. Any tools, interventions, and management practices must also consider the economic security and solvency of ranching families.

Systems-Based Farm Management

Incremental Solutions To Accelerate

- Ability to market cattle products based on a suite of sustainable management labels, like existing organic or grass-fed.

Transformational Solutions To Create

- Systems-analysis tools that integrate data across the farm production system and recommend management practices that maximize environmental and economic benefits; tools should also consider and recommend alternatives to traditional meat processing models such as cooperative, local, mobile, on-farm, and others to increase resilience of the farm distribution system in the face of challenges such as pandemics.

Next Era Concepts

- Systems-analysis tools that enable design and optimization of diversified farming systems that integrate data across the ag production chain including multiple animal and cropping systems, silvopastoral practices and agroforestry, advanced grazing management, multiple marketing opportunities, distribution, and societal demands and impacts.

Gaps, Barriers, and Hurdles

Research - Research is needed to develop more circular economic approaches that limit on-farm waste, develop new waste markets, and/or repurpose or reuse waste for value-added products or energy production. Integrate farming activities with urban centers, such as diverting food loss and waste from urban centers to animal feed that replaces grain-based feed with human-inedible resources, or usage as a feedstock for production of bioenergy or other value-added products.

DAIRY – PRODUCTION

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

Genome Design

Incremental Solutions to Accelerate

- Genomic analyses of all breeds used for U.S. dairy production.
- Defined milk components that effect human health, so these can be targeted as phenotypes (current Dairy Grand Challenge).
- Genomic analyses for feed efficiency.
- Reduced cost semen sex selection technologies.
- Genomic selection of embryos combined with cloning and embryo transfer technologies.
- Efficient technologies for multiple gene edits in a single animal.

Transformational Solutions To Create

- Dairy cows with increased milk production capacity; e.g., increased fertility and longevity that reduce the ratio of non-productive to productive years.
- Cattle with lower enteric methane emissions and improved feed efficiency.
- Cattle with strong immune systems that reduce the need for antibiotics and have increased resistance to infections/diseases, particularly mastitis.
- Healthier animals that require fewer calories with lower mortality and increased growth rates.
- Forages and feeds with improved nutritional content and digestibility.

Next Era Concepts

- Technologies that bring cows to milk without birthing a calf to reduce over-breeding of calves and extend cow longevity.
- Co-breeding of crops and animals to deliver optimal feed and animal genetics that maximize nutrient use efficiency while minimizing enteric methane emissions.
- Designed microbiome that increases nutrient use efficiency and improves animal health, with reduced enteric methane production.

- Public acceptance of gene editing technologies for dairy cattle.

Gaps, Barriers, and Hurdles

Research - There are four key areas where innovations in the dairy system are expected to significantly increase productivity and deliver environmental benefits, including productivity, enteric emissions, feed production, and manure and nutrient management.

Research - Improve precision genetics (i.e., gene editing) to increase outputs of protein per animal unit to allow a decrease in animal numbers to produce equivalent amounts of high-quality food.

Research - There is a significant challenge to integrate 'omics datasets (genomics, proteomics, metabolomics, and transcriptomics) with high-throughput phenotyping and AI to uncover important quantitative trait polymorphisms that can be used to improve genomic prediction. Accelerate genetic improvement in sustainability traits (such as fertility, improved feed efficiency, welfare, and disease resistance) in livestock, poultry, and aquaculture populations through the use of big genotypic and sequence datasets linked to field phenotypes and combined with genomics, advanced reproductive technologies, and precision breeding techniques to enable a 10-fold increase in the rate of genetic improvement. Multidisciplinary programs between veterinarians, microbiologists, animal nutritionists, and breeders are needed. Develop more rapid assays to accelerate phenotyping and introduction of multigene traits in animals. A better understanding of the animal microbiome is needed, including relationships to animal health, nutrient utilization, and enteric emissions.

Regulatory – Overcome regulatory hurdles to allow for a risk-based approach that takes into consideration the familiarity or complexity of the genetic changes. harmonize the regulation of genome editing in food species, especially for plants and animals that could otherwise have been developed through traditional breeding techniques. Having a much higher and disparate regulatory barrier for genome edits in the animal kingdom is not scientifically justifiable from a risk perspective, and needlessly disadvantages both U.S.-based animal genetic researchers, and more generally American animal agriculture. USDA-APHIS is the appropriate agency to oversee genome editing in plants and animals for agricultural purposes that could otherwise have been developed through traditional breeding techniques. FDA's proposed approach to regulate intentional genome alterations in food animals as drugs is a regulatory hurdle that will disadvantage uniquely both the U.S. researchers and animal agriculture.

Digital and Automation

Incremental Solutions To Accelerate

- Cow movement and milk in-line hormone monitoring to better track the estrous cycle of dairy cattle.
- Tracking feed intake of cattle on pasture (Munchinator).
- Optimizing milk production using robotic milking including improving individual cow behavior.

Transformational Solutions To Create

- Health sensors on individual animals that enable preventative/proactive treatment so that a level of illness does not get to a point of major stress on the cow or animal; e.g., biosensors that serve as color-changing biotattoos that inform physiological changes, such as detecting increased lactate in dairy cattle (an indicator of developing low milk yield) or cortisol, and indicator of stress.

- Real-time testing of feed ingredients with appropriate ration adjustments to maximize the production of each dairy cow.

- Real-time detection of mycotoxin and other harmful compounds during harvest to prevent even low levels of these compounds from affecting production when fed.

- Real-time monitoring of harvest to optimize the feed value and digestibility of forages and grains.

- Animal facilities and environments designed to minimize stress and maximize animal well-being and productivity.

- Real- time monitoring of rumen metabolites that affect milk production efficiency (e.g., ratios of propionate, acetate, butyrate, branched chain fatty acids)

- Validated monitoring method for estrus detection.

Next Era Concepts

- Low-cost, easy-to-use and broadly dispersed diagnostic sensors that provide real-time, animal specific data that inform animal health, stress levels, and presence of pathogens or disease.

Gaps, Barriers, and Hurdles

Research – Develop a range of sensors and data flows to capture data and create information on behavior and well-being of animals to improve management of livestock. Sensors must be robust, able to function in a range of challenging environments and provide data at costs that make them viable. Many novel technologies are too expensive for commercial livestock producers and lack a user-friendly interface to facilitate their adoption. Develop adoption incentives, technical support, and education. The University extension systems play a key role here.

Research – Develop standards to enable design and implementation of interoperable sensors and decision support tools. Sensors and digital solutions should be scale-neutral, affordable, and available to all farmers. Developing sensors and digital ag technologies will require truly trans-disciplinary research among researchers and more trans-disciplinary training of students and the associated workforce.

Research - Additional research is needed for developing biosensors that monitor individual animal health and performance. For instance, biotattoos sample various bodily fluids such as sweat, saliva, or tears and inform physiological status and well-being. Information can be transferred via cell phone to create a timestamp as well as geographic coordinates that could be utilized for more effective local, regional, and national coordination of overall stress or developing disease (NAS, 2019).

Research - Develop reliable biomarkers to help determine what types of housing facilities are best suited for animals; design professionals could combine this information with their understanding of efficiency of operations, disinfection procedures, and worker safety and health to improve animal facility design that integrates sensors and electronic monitoring and improving animal health and well-being. For instance, sensors in all animal rooms that are tied to the air handling and lighting systems to ensure optimal temperature, humidity, and ambient light. Visual analysis of behavioral cues that inform expression of innate behaviors, and appropriate interventions such as activating access to an outdoor yard so that animals can be fulfilled.

Prescriptive Intervention

Incremental Solutions To Accelerate

- Feed rations that are more precisely formulated to maximize utilization efficiency and minimize negative environmental impact, and technologies that can more precisely deliver feed to animals on an individualized basis

Transformational Solutions To Create

- Decision support tools that enable daily monitoring of the 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.

- Feed rations, formulations and additives that minimize enteric methane emissions while maximizing nutrient acquisition and animal performance.

Next Era Concepts

- Prescriptive livestock farming (PLF) systems that enable individual-animal-targeted nutrition, health, and welfare (NAS, 2019).

Gaps, Barriers, and Hurdles

Research - Already today, most dairy farms manage multiple technologies that collect data and are expected to analyze past trends and future probabilities to make decisions/recommendations. As more data and information are collected, the ability to do this becomes more and more difficult. Developing computerized systems, models, and dashboards becomes helpful and, as we continue to gather more and more information, necessary. It is one thing to identify that there is a potential problem coming; it is a completely different matter to analyze all the options and come up with a way to address the problem without significant unintended consequences. The usage of machine learning and artificial intelligence will become more and more important to develop the "smart" systems needed for the future. One of the key areas of research and practical development in this area is capturing the knowledge and experience of the current generation of farmers and dairy experts before we lose the collective knowledge of this generation.

Research - The objective of prescriptive livestock management is to create a management system based on continuous automatic real-time monitoring and control of production/reproduction, animal health and welfare, and the environmental impact of livestock production. Monitoring can be done remotely through sounds, sights, animal movements, and estimations of environmental parameters such as temperature, humidity, or air particulates. Investigation of specific sounds using continuous monitoring systems such as AI to uncover patterns that inform optimal growth, well-being or signs of stress, such as early coughs experienced in bovine respiratory disease and/or maternal well-being. The biggest obstacle for precision livestock farming is the data science challenge of transforming multiple types of data from various sensors and sources into knowledge. This knowledge could then be used to accurately predict a genetically superior animal, an animal in distress or presenting disease symptoms, or an abnormal state that requires farmer intervention. Developing farmer-friendly, cost-effective plug-n-play precision livestock farming applications will require collaboration among animal scientists, agricultural engineers, and data scientists focused on a shared vision of animal-centered care. There is insufficient focus in current funding calls on bringing together the disparate disciplines needed to address complex problems using data science. (NAS, 2019).

Research - It will be important to develop strategies to decrease the use of antibiotics in food animals without negatively impacting productivity, animal health, or animal welfare. Developing alternatives to antibiotics is dependent, in part, on basic research that better defines the processes important to pathogenesis, thereby enabling development of more targeted interventions and solutions. Identify and avoid subclinical, inflammatory mechanisms in livestock to enable producers to avoid losses by melding immunology, endocrinology, and metabolism to improve health and well-being of livestock. Enable better disease detection and management using a data-driven approach through the development and use of sensing technologies and predictive algorithms. Sensors and the data they provide combined with data science holds great potential to improve understanding of population dynamics in animals and improve their well-being and productivity.

Regulatory - Collaboration across Federal agencies to facilitate the adoption of technologies that fall under the regulations of different agencies is vital. For example, many feed additives that reduce enteric emissions are regulated by the Food and Drug Administration. The industry is very interested in this technology and the impact it can have on reducing enteric emissions, but the industry cannot adopt the technology unless approved by the FDA. Through interagency collaboration involving FDA and other agencies, viable ag technologies can proceed through the regulatory process is a timely manner.

Systems-Based Farm Management

Incremental Solutions To Accelerate

- Systems-analysis tools that 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.

Transformational Solutions To Create

- Integrated data generation and decision-making tools that combine monitoring and data analysis in real time to optimize productivity.

Next Era Concept.

- None listed.

Gaps, Barriers, and Hurdles

Research - Research is needed that captures the environmental and economic outcomes of implementing technologies and conservation practices that impact water quality, greenhouse gas emissions, and manure and nutrient management.

Research - Objective, scientific standards for animal welfare need to be developed and applied that allow for quantifying animal health and impacts of various management practices. Need to determine how those standards can be incorporated into precision livestock systems, and how the social sciences can inform and translate scientific findings to promote consumers' understanding of trade-offs and enable them to make informed decisions.

Other - As new, innovative technologies and practices develop, the industry looks to USDA programs to support the deployment and adoption among producers. Whether it is USDA research efforts that enable creation of innovative advances, Farm Bill conservation programs, loan programs or technical assistance that accelerates the acceptance, adoption and deployment of those innovations, USDA is an integral partner to support the dairy industry efforts.

DAIRY – PRODUCTION CAPABILITY

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

Genome Design

Incremental Solutions To Accelerate

- Gene modifications in forages that reduce lignin or alter tannins or other compounds that shift rumen metabolism to optimum volatile fatty acid production and reduce deamination reactions. These changes are specifically designed to optimize milk production, reduce manure, and nitrogen excretion.

- Genomic selection for feed efficiency in dairy cattle.

- Plants gene edited for phytase or other mechanisms to increase phytic acid digestibility and reduce phosphorus contamination.

Transformational Solutions To Create

- Forage or feed crops with improved resource use efficiency, disease and stress resistance, and improved nutritional content and digestibility.

- Cover crops 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.

- Microbiome technologies that reduce deamination of feed proteins and increase the digestion of phytic acid. Will reduce nitrogen and phosphorus contamination from manure.

Next Era Concepts

- Soil microbiome that enhances capture and availability of nutrients to increase feed production efficiency and reduce losses to the environment.

- Corn that fixes nitrogen using gene editing.

Gaps, Barriers, and Hurdles

Research - Develop forage, feed, and cover crops within the context of advanced soil health management practices such as regenerative, conservation agriculture and other agroecological cropping systems to maximize soil and environmental benefits using crop genetics.

Digital and Automation

Incremental Solutions To Accelerate

- Define "soil health indicators," especially those relevant to Ecosystem Service Markets or Carbon Credit Markets, and establish standards for their quantification and reporting.

- Affordable, automated, validated, methane measurement at the barn level.

Transformational Solutions To Create

- In-field sensors that monitor soil and feed crop conditions as well as nutrient levels and use.

- In-field sensors that monitor soil carbon content, greenhouse gas (GHG) losses and other environmental services to validate carbon sequestration efforts, evaluate impact of various management strategies, and enable Ecosystems Services and/or Carbon Credit Markets.

- Edge of field sensors that detect nutrient losses and monitor the success of mitigation efforts to improve nutrient capture and use.

- Validated models and technology for field-based sensing of forage quality and yield to quickly identify issues in the field or manage harvest/grazing timing.

- Affordable automated methane measures at the individual cow level.

Next Era Concepts

- Broadly distributed, low-cost, biodegradable sensors and biosensors that quantify and inform crop and soil health indicators with high temporal and spatial resolution.

Gaps, Barriers, and Hurdles

Research - Develop and promulgate soil health testing protocols, including suites of tests that farmers can replicate easily and cheaply on cropland, grassland, and forest land to understand, monitor, and track changes in soil health. Need to harmonize data collection, sample analysis, measurement and reporting for both the public and private entities to aid efforts aimed at measuring the environmental impacts of various management practices and enabling Ecosystem Service Markets and Carbon Sequestration Credit markets.

Research - Develop a better understanding of water-quality implications of advanced practices and technologies and support the calibration and validation of existing water-quality models.

Prescriptive Intervention

Incremental Solutions to Accelerate

- Increase adoption of practices like perennials, cover crops, and intercropping that improve the soil functions that help increase yield, nutrient use efficiency, and water management.

Transformational Solutions To Create

- Technologies that reduce odor, ammonia, nitrous oxide, hydrogen sulfide, methane, and non-methane gasses from cattle (as well as pigs and poultry) and manure for reduced emissions and improved quality of life in rural communities.

- Real-time data on soil health indicators and a suite of amendments, biostimulants, and products recommended for improving soil health (e.g., on-farm usage of manure or other amendments that improve soil health, quality, and stability).

- Validated models and technology for field-based sensing of forage quality and yield that quickly identify issues in the field and/or manage harvest/grazing timing.

Next Era Concepts

- Use of soil microbial interventions that reduce weed stress on crops and increase nutrient use and efficiency.

Gaps, Barriers, and Hurdles

Research - Develop an increased understanding of technologies and conservation practices that relate to manure management, leading to reduced environmental impacts and improved utilization of nutrients contained in manure. As an example, Newtrient created a Technology Catalog that provides dairy farmers with information, updates, case studies, and evaluations of manure management technologies. Has a team of globally respected academic and technical experts (the Technical Advancement Team) that evaluate and score technologies based on clearly defined criteria. The goal is to identify and implement the most impactful solutions that maximize environmental and economic benefits for farmers.

Systems-Based Farm Management

Incremental Solutions To Accelerate

- Broader implementation of technology and management paradigms that improve cropland management, such as alfalfa crop varieties for reduced harvest frequency to prevent soil compaction.

Transformational Solutions To Create

- Systems-based whole farm modeling that 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, increase environmental benefits, and quantifying these benefits to enable Ecosystem Service Markets or Carbon Sequestration markets.

- Incentivized on-farm production of energy (e.g., agrivoltaics, biogas, wind farms) that reduces net carbon emissions and farm waste while maximizing production and environmental benefit; e.g., integrate livestock into solar fields.

Next Era Concepts

- One hundred percent perennial dairy production systems that can achieve net-zero nutrient loss and provide sufficiently nutritional forages for modern production levels.

Gaps, Barriers, and Hurdles

Research - The dairy industry has already set aggressive new environmental sustainability goals to become carbon neutral or better, optimize water usage and improve water quality by 2050, thus directly aligning with goals of the AIA. Promising areas of research that offer significant environmental benefits include changes in dairy feed production practices and use of new manure-based products (created by innovative manure handling and processing technologies) in place of traditional dairy manure and commercial fertilizers. A priority of the dairy industry is to quantify the impacts of adopting no or minimal tillage, cover crops, innovative crop rotations, and novel fertilizer sources (including new manure-based fertilizer products) on the following: (1) Soil carbon sequestration potential, including impacts of manure-based fertilizers on long-term soil carbon in dairy forage-based cropping systems (e.g., corn silage and alfalfa); (2) Environmental and agronomic outcomes of field-scale research on the impact of dairy manure-based products as soil amendments on GHG emissions, water quality, and water productivity of forage cropping systems, and (3) Soil health benefits, particularly the influence of dairy manure-based agronomic practices on soil microbial communities and their beneficial ecosystem services. Research in these areas also offers opportunities to create new revenue sources such as manure-based products or enabling of Ecosystem Service Markets or Carbon Sequestration Markets.

Other - The U.S. dairy industry developed the Farmers Assuring Responsible Management (FARM) program to help educate the public that the dairy industry is taking the very best care of cows and environment, producing the best milk with integrity. These educational and outreach programs are essential for informing the public and increasing awareness of farm production processes and the economic, environmental. and societal benefits they deliver.

Other – Offer financial incentives to farmers for adopting sustainable and regenerative approaches.

DAIRY – MARKET EXPANSION AND DIVERSITY

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

Genome Design

Incremental Solutions To Accelerate

- Explore milk characteristics that contribute to human health so they can be used as phenotypes in genomic analysis.
- Genetic merit breeding value calculations for Net Merit (NM$), Cheese Merit (CM$), Fluid Merit (FM$), and Grazing Merit (GM$).

Transformational Solutions To Create

- Dairy cows that are more resistant to heat, leading to increased milk production in impacted regions or expanding into new geographic production areas.
- Microbes with elevated hydrolysis and methanogenesis for increasing yield of methane from anaerobic digestion.
- Lignin degrading enzymes from rumen microbiome to improve the biofuels industry.

Next Era Concepts

- Designer milks for various human health outcomes.

Gaps, Barriers, and Hurdles

- None listed.

Digital and Automation

Incremental Solutions To Accelerate

- Increased automated measures combined with decision support to help farmers increase production and reduce labor. More reliable automated milking systems.
- Automated measures of milk components (oligosaccharides, branched chain fatty acids, immune compounds) that have beneficial human health effects.

Transformation Solutions To Create

- Real-time monitoring of manure nutrients and components, and automated processes that assist with manure management and treatment.

- Blockchain or similar technology that enables traceability throughout the food production system.

- Sensors that detect and inform the presence of pathogens and diseases, including zoonotic diseases, across the supply chain, from animals to animal-based products.

- Digital technologies and automated processes that address labor shortages and safety.

Next Era Concepts

- Comprehensive monitoring system that tracks animal health, well-being and presence of pathogens integrated with a global surveillance system to detect emerging biological threats, track their global movements, and anticipate mitigation strategies to minimize losses and increase public safety and economic prosperity.

Gaps, Barriers, and Hurdles

Research - Evaluate and upscale new innovative dairy manure management technologies (see Prescriptive Intervention for additional information).

Research - Expand research on developing and implementing national and international disease tracking systems, such as the National Bio and Agro-Defense Facility (NBAF) and the Global Surveillance System (GSS), to detect and block transboundary animal diseases such as avian influenza or foot and mouth disease. Align digital technologies with One Health Initiatives and strengthen capacities for surveillance of zoonotic infections and bolster the ability of existing State and Federal laboratory networks to rapidly detect, report, and respond to new emerging biological threats.

Research - As labor availability continues to be a primary concern across multiple segments and geographies in the ag supply chain, the promise of digital technology and automation holds promise for many areas of production and processing.

Prescriptive Intervention

Incremental Solutions To Accelerate

- Improved quantification of manure nutrient availability matched to field application and timing associated with crop nutrient demands.

Transformation Solutions To Create

- Diversified opportunities for using manure as a feedstock for value-added products such as fertilizers or energy production.

- Identify areas along the food production chain where rapid changes and interventions can be implemented to re-route or re-distribute food rapidly when market accessibility changes.

Next Era Concepts

- On-farm manure processing and use technologies that extract nutrients for recycling as fertilizers and use carbon for energy generation and/or carbon sequestration.

Gaps, Barriers, and Hurdles

Research - Develop new value-added uses for manure, such as manure-based products or feedstocks for bioenergy (e.g., clean energy production from anaerobic digestors, renewable fertilizers from manure that also improve soil health and long-term carbon capture, etc.). As an example, manure processing using thermal evaporative technology to produce dry solids containing all nutrients except ammonia nitrogen, aqua ammonia, and recyclable water. The dry solids and aqua ammonia show promise to meet organic fertilizer certification requirements. These new manure-based products can be used on and off farm, displacing commercial fertilizers, providing new sources of off-farm revenue, and allowing the farm system to operate in a more circular, sustainable manner. Anaerobic digesters have worked well for dairy, but are not as amenable to cattle feedlots. Expand research to help with manure management related to feedlots to reduce emissions from cattle manure and provide additional value to this waste stream.

Research - Evaluate technologies and systems that produce renewable energy from waste streams with the goal of developing recommendations on the use of financial incentives to achieve maximum environmental benefits.

Research - Practices and technologies exist today for dairy farmers to lower their carbon footprint and improve water quality but require further development, significant on-farm operational changes, investment and advanced technical assistance that limit widespread farmer adoption. Need technologies that not only accelerate improvements, but also enable nimble adaptation and focus on technologies that can be scaled for maximum impact.

Systems-Based Farm Management

Incremental Solutions To Accelerate

- Systems-based whole farm predictive tools to assess tradeoffs of management interventions on productivity and environmental impacts.

- Ability to market dairy products based on suite of sustainable management labels, like existing organic or grass-fed.

Transformational Solutions To Create

- Systems-based whole farm predictive tools that collect, integrate, manage, and analyze on- and off-farm data in real time for practical and prescriptive management interventions to improve the economic and environmental performance of dairy farms.

Next Era Concepts

- Optimization procedures that assess animal, crop, and ecosystem service production enterprises on the farm to maximize farm economics.

Gaps, Barriers, and Hurdles

Research - Determine the impacts of dairy manure-based amendments, including new manure-based fertilizer products generated from advanced treatment technologies, with consistent qualitative characterization of long-term soil carbon for optimizing their use in crop production; quantify the impacts of dairy manure-based products as soil amendments on greenhouse gas (GHG) emissions, water quality, and soil health and productivity, including effects on the soil microbiome, to improve systems-based analysis and optimization of the dairy farming system.

Research - Consider circular economic approaches such as inclusion of food waste and/or biosolids for anaerobic digestion or thermal processing to detoxify pharmaceuticals and PFAS and produce additional renewable resources. For instance, external waste streams might be incorporated into on-farm digesters to increase renewable energy production and receive additional GHG credits from waste that would otherwise be sent to the landfill or land applied. Conduct research that identifies the benefits of combining wastes and maximizing treatment systems to quantify the potential impact of a systems approach to the management of organic waste.

Research - Cost-benefit and value chain analyses should include social dimensions to define the enabling environment for adoption of practices. Get consumer preference dollars to farmers.

Other - De-risk new and innovative approaches and technology by allowing farmers to receive cost-share to try these approaches that are improving environmental outcomes.

APPLIES TO ALL OTHERS – 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.

Genome Design

Incremental Solutions To Accelerate

- Establish data collection and management standards for high-throughput sequencing, genotyping, phenotyping, and field-based studies to harmonize data.

- Link government, public, and private sector-supported databases.

Transformational Solutions To Create

- Collect and manage high-throughput sequencing, phenotyping, genotyping, and field-based studies using harmonized, standardized methods to populate centralized and/or interlinked databases.

- Centralized (virtual), interconnected repository of high-quality, interoperable data from genomics, phenomics, metabolomics, and field studies to enable deep data analytics (e.g., NSF, ARS, USFS FIA, CyVerse, MaizeGDB, DGIL Porcine Translational Research Database, FAANG, "Crops in Silico,", TreeGenesDB, recent and historical field studies, etc.).

Next Era Concepts

- Digital crop designs with desired phenotypes based on Genotype, Environment, Management, and Socio-economic (GxExMxS) analysis (e.g., use of model-based metabolic engineering of resource allocation across a wide range of plants to design crops with increased yield and increased nutrient density).

- With a comprehensive understanding of phytobiome components and their interactions, design and optimize genetics of the phytobiome "phenotype" to enable maximal farming system production and production capability.

Gaps, Barriers, and Hurdles

Research - Develop and promote the adoption of science-based, community-developed standards for collecting and curating crop genomic, phenomic, and field-related data into centralized, broadly available databases. An interconnected system of harmonized data will enable deep analytics to uncover novel relationships between genes, phenotypes, environment, management, and socioeconomic factors.

Regulatory - Blanket agreements are needed to encourage farmers, ranchers, and processors to share their operational and management data to advance science, while protecting this shared data from being used against the individuals that shared the data or the industries they represent.

Digital and Automation

Incremental Solutions To Accelerate

- Establish clear standards that 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.).

Transformational Solutions To Create

- Automated or semi-automated data collection tools for submitting survey and other farm-level or forestry-related data (quantified and verified) to the USDA using safe, secure, standardized protocols with opt-in/out participation.

- Front-end digital hub where data can be submitted to USDA. This hub would be accessible by various subagencies. An interoperable system like this would lessen the burden resting on growers to submit redundant data to multiple subagencies.

- Blanket agreements that encourage farmers, ranchers, and processors to share their operational and management data to advance science, while protecting this shared data from being used against the individuals that shared the data or the industries they represent.

Next Era Concepts

- Two-way exchange of standardized, interoperable data between USDA and end-user community using safe, secure, standardized protocols that inform local production choices with opt-in/out participation.

Gaps, Barriers, and Hurdles

Research – Develop cloud computing-based databases to store, manage, and share different types of data (molecular, phenotypic) of forest trees. Explore current resources developed by universities and private entities. The community should be able to access such resources to develop solutions related to forest health and productivity. Support some databases such as the CartograTree DB (https://treegenesdb.org/ct).

Research - There is broad support for establishing an open digital platform that integrates the widest range of agricultural data, devices, and experts from across the agricultural ecosystem. These platforms would enable artificial intelligence-driven insights to achieve the most effective approach of accelerating and democratizing agricultural innovation. Develop a common digital vocabulary or data dictionary (standards) through community contributions. The data dictionary should be platform agnostic and publicly embraced to avoid siloed and duplicated initiatives. Open industry standards are foundational for system interoperability and must be at the top of the priority list for sensor/IoT to work at scale throughout the industry. Create a common data repository and maintain using FAIR (findable, accessible, interoperable, reusable) standards. Develop universal ag data standards for data collection and formatting in cooperation with the scientific community and include, for example, crop rating scales for breeders, metrics for soil traits, and formatting for data collected from sensors. USDA has an opportunity to lead the creation and management of a data repository for ag data and integrate across "One-USDA" to link agencies and agency databases.

Regulatory – Develop blanket agreements to encourage farmers, ranchers, and processors to share their operational and management data to advance science, while protecting this shared data from being used against the individuals that shared the data or the industries they represent.

Other - Robust farm productivity and practices statistics - including conservation practice adoption, crop rotations. cover crop use, fertilizer and organic amendment use, chemical use, irrigation practices and farm energy and equipment use are critical for measuring progress towards the AIA goals. USDA surveys such as Census of Agriculture, Irrigation and Water Management Survey, and Agriculture Resources Management Survey, and other annual USDA National Agricultural Statistics Service surveys provide useful data to help evaluate the impact of production practices at the State and national scale, but there are gaps and disparities that have led to a patchwork of practice information for many crops that hinders research and understanding of actual adoption of practice on the farm. Investment is needed in data collection, statistical analysis, and educational outreach to increase grower participation in these surveys. Further, USDA should take steps to standardize data collection and formatting across subagencies to minimize duplicative reporting. USDA should consider private-sector data collection tools to advance opportunities for developing automated reporting systems, which could save time and provide value for growers while strengthening the volume and accuracy of real-time data available to USDA. Integrate data collection efforts such as the USDA Forest Service Forest Inventory and Analysis (FIA) program, USDA, Farm Service Agency programs and USDA National Agricultural Statistics Service's Census of Agriculture. Increase data collections from more sources; e.g., USDA's Tenure, Ownership, and Transition of Agricultural Land (TOTAL) surveys are conducted every 5 years but need to be expanded to cover all 50 States; the National Resources Inventory could be expanded to include more sampling locations; data on crops such as sugarbeet production are already collected by farmers and should be included more broadly in USDA data collections.

Other - The dairy industries (and others) use USDA survey data to measure progress towards goals, evaluate impacts of management practices, and conduct the Life Cycle Assessment of Fluid Milk. This includes NASS Census of Agriculture, the Agriculture Resource Management survey, and the Farm and Irrigation Management Survey. These surveys provide aggregated, sector-wide insight to practice adoption and management systems, but should be expanded to collect data regarding use of a manure product as fertilizer and to cover additional information about alfalfa and corn silage. Reduce the time between data collections and availability of data to the public.

Other - Given online data systems of both precision ag companies and USDA-FSA, it is possible with modest software changes to create, where the producer gives consent, a seamless data flow between the entities, which could reduce the workload for the producer and USDA field staff, allowing both to focus on higher value jobs. Data sources can be proprietary, so collecting all the information in one place that also respects producer privacy is a challenge. A facilitated public-private planning effort that also includes land-grant universities and stakeholders could help to overcome these challenges. As an example, a two-way application programming interface (API) would require a USDA API so that precision ag companies could interface with USDA and a secure database where USDA could store sensitive customer data. The API could expand to a two-way API between USDA and the precision ag company, where data could be pushed back and forth based on customer consent.

Other - Farmers should be able to access USDA research data through existing or expanded channels such as climate hubs, LTARs, or ARS PDIs.

Other - It will be essential to develop a workforce that can support the emerging digital farming paradigm, particularly for rural communities. Workers need a higher understanding of systems, computing, data, and AI. Engage the younger generation through organizations such as "FIRST" (For Inspiration and Recognition of Science and Technology).

Prescriptive Intervention

Incremental Solutions To Accelerate

- None listed

Transformational Solutions To Create

- Availability of standardized, interoperable data and protocols for third-parties to develop decision support tools or other digital ag products that maximize data usage to improve for environmental, economic, and social benefits.

Next Era Concept

- Develop easy-to-use, publicly available data repositories that agricultural producers and processors can contribute to without being mandated to do so or having their contributions used against them in the future.

Gaps, Barriers, and Hurdles

Other - Re-frame agriculture and forestry data as a public resource that can and should be leveraged to serve public needs in a way that also directly benefits producers and give producers control of data transactions involving their own data. All publicly funded ag and conservation data should be accessible through farmer and rancher-focused tools designed to reduce risk, improve conservation outcomes and benefit production. Historical weather and market data are of utmost importance to nearly everyone in the ag space for proper planning, analysis and benchmark decision making, but data accessibility is mostly closed and proprietary. To stimulate innovation, make these data easily and freely available, platform agnostic, based on defined, open standards such that technology vendors can quickly and consistently provide analysis services to the ag community.

Other - While USDA has long been a pioneer in providing transparent estimates of crop production, NASS could partner with private-sector actors to improve survey methodologies, which would enable producers to have more timely estimates of grain production and as a result make more profitable crop marketing decisions. Farmers stand ready to participate more directly in this critical crop forecasting process and the USDA could deploy mobile applications that allow them to directly contribute field observations in a modern, give-to-get data sharing program. USDA should fill data gaps. For example, cross-cutting data within the agencies, such as with USDA Risk Management Agency (RMA) data for field boundaries, could be digitized with an option for growers to opt-in or opt-out depending on personal preference and convenience, with the right privacy protections in place. More open access to RMA data like historical yields could provide a level playing field for innovation and the development of insights that can help farmers increase productivity with fewer inputs.

Other - The AgTech ecosystem is robust, but integration of digital tools remains a struggle. There may be 20 different software solutions that are accomplishing nice solutions to problems for growers, but they don't integrate together into an enterprise system.

Other - Understanding the ethical and societal implications of data technologies like AI is critical to mitigate bias, assure accountability, improve transparency, and deliver robustness to ensure everyone benefits. Data technologies are intended to help farmers, foresters, ranchers, and processors make better decisions, but not all farmers have access, experience, and training. This is a primary reason that USDA should be responsible for housing the centralized and integrated data repositories and hosting an agricultural decision support informatics platform that provides state-of-the-art decision support tools and models and linkages to experts and highly organized extension and outreach materials.

Systems-Based Farm Management

Incremental Solutions To Accelerate

- Continued development and expansion of public-private partnerships such as the USDA Partnerships for Data Innovations program.

Transformational Solutions To Create

- Centralized (virtually) repository of high-quality, interoperable data from across the entire ag value chain that enables deep systems analysis. Examples include genomics, phenomics, environmental data, management data, soil health indicators, microbiome, yield data, demographics, production processes, post-harvest processing, distribution, transportation, policies, social data, and marketing data.

Next Era Concepts

- Systems analysis tools that identify deep linkages between disparate datasets, enabling modeling and design of optimized ag systems that maximize economic, environmental, and societal benefits.

Gaps, Barriers, and Hurdles

Other - To truly leverage the power of systems analysis, high-quality, interoperable data sets are needed across the entire ag value chain. USDA is uniquely qualified to provide leadership in the development and housing of such authoritative data (e.g., what crops are grown where, plant date, harvest date, yield, pest pressure, where and how pesticides are being applied, etc.), while protecting grower privacy. USDA is home to a vast resource of agricultural data collected from producers by various agencies. Increased integration and analysis of this ag data is key to supporting innovative analyses by university researchers and delivering transformative breakthroughs. By integrating and creating a secure, multi-layered querying system, government and land-grant university researchers will be able to simulate and evaluate real-time crop growth, risk, financial market impact, water quality and quantity impacts, and climate change mitigation and adaptation options. This requires a strategy where data collection experiments are designed to inform models, which can then be used to scale results. Further integration of regional farm-level data, remotely sensed data, weather data, futures market data, and other public and private data enable predictions and analyses that will benefit the entire ag supply chain, as well as taxpayers and the environment. Government programs such as the ARS Partnerships for Data Innovation, Climate Hubs, and the Long-Term Agroecosystem Research (LTAR) networks provide a key interface between these data sources and end-users, which could be further strengthened by partnering with other public/private organizations working on similar efforts to deliver data-driven solutions to farmers, foresters, and ranchers.

Other - USDA can energize the innovation environment in multiple ways to help achieve the goals of the Agriculture Innovation Agenda (AIA), including enabling the creation of innovative advances, Farm Bill conservation programs, loan programs, technical assistance, de-risking innovation by cost-share of new approaches, measuring the impact of approaches to develop recommendations and best management practices, and establishing policy and regulations that are conducive to an innovating environment that maximizes economic, environmental and social benefits. USDA should further invest in and elevate the work of existing functions within the agency, including but not limited to the regional USDA Climate Hubs and the NRCS Soil Health Division. Ensuring effective cross-agency communication, collaboration, and data sharing is key to effectively utilizing USDA expertise to implement and achieve an agencywide, climate-smart research and action agenda. While developing new technologies and practices is important, it is only part of the equation. Ensuring that USDA agencies have the capacity to implement the AIA is equally critical and needs attention and investment.