

**Climate Change Science White Paper**  
**U.S. Department of Agriculture**  
**Research, Education and Economics**  
**Office of the Chief Scientist**  
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There is considerable science-based evidence that the global climate is changing, with increasing overall temperatures, increasing carbon dioxide (CO<sub>2</sub>) and other greenhouse gases (GHGs), and altered patterns of precipitation (Backlund et al., 2008). Most of the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic GHG concentrations (Pachauri & Reisinger, 2007). The average temperature in the United States has risen more than 2°F over the past 50 years and is projected to rise more in the future; how much more depends primarily on the amount of heat-trapping gases will be emitted and how sensitive the climate will be to those emissions (Karl et al., 2009).

Furthermore, patterns of land use, agriculture, forestry, and grazing land management in the United States and globally are shaped by and contribute to climate.

A 2008 assessment by the U.S. Climate Change Science Program makes clear the scope of the challenge climate change presents to agriculture (Backlund et al., 2008). Among that report's overarching conclusions, three assessed as being very likely are among the most important and demand preparation by the agricultural sector:

- Climate changes—temperature increases, increasing CO<sub>2</sub> levels, and altered patterns of precipitation—are already affecting U.S. water resources, agriculture, land resources, and biodiversity.
- Climate change will continue to have significant effects on these resources over the next few decades and beyond.
- The effects of climate change on ecosystems will affect the services that ecosystems provide, such as purifying water and removing carbon from the atmosphere, but we do not yet possess sufficient understanding to project the timing, magnitude, and consequences of many of these effects.

Thus, climate change introduces major uncertainties into the planet's current and future capacity to produce food, feed, fiber, and fuel for the ever-growing population. Furthermore, agriculture produces approximately 10–12 percent of the world's total anthropogenic GHGs (2005 figures; Smith et al. 2007). In the interest of stabilizing global climate as well as limiting losses of carbon from agriculture in the interest of production efficiency, the capacity to produce agricultural commodities must not be accompanied by proportional increases in GHG emissions from agricultural production systems. The ability of the agricultural sector in countries around the world to produce sufficient commodities for humanity without increasing the GHG footprint depends on the scientific community's ability to produce new information and technologies that reduce climate-related production uncertainties and provide production methods and tools to support production decisions on a scale from individual farms to the global landscape and economy.

### **Current State of the Science**

In 2002, the United States produced crops and livestock worth approximately \$200 billion in a wide array of environments and soil types (Backlund et al., 2008). At the same time, agriculture

is responsible for approximately 6 percent of the nation's GHG emissions (Environmental Protection Agency, 2010). Unlike emissions from fossil fuel use, the contributions of CO<sub>2</sub> to the atmosphere from land use activities are potentially reversible. The dominant drivers of land-use emissions of CO<sub>2</sub> are the conversion of forest and grassland to cropland and pasture, the depletion of soil carbon through tillage, wetland disturbance, and catastrophic disturbances such as fires and hurricanes. Management practices show promise for restoring the terrestrial carbon storage, and these approaches need to be developed for wide application.

Land use practices such as livestock grazing, some manure management practices, and soil fertilization also affect emissions of other GHGs such as methane (CH<sub>4</sub>) and nitrous oxide (N<sub>2</sub>O). Agriculture and forestry land management practices are needed that lower GHG emissions or increase the quantity of carbon stored in soils and vegetation, or both. These include shifting cropland into forests or permanent grasslands, managing existing forests to store additional carbon, adopting no-till or reduced tillage systems on a long-term basis, eliminating fallow periods, planting cover crops, changing nitrogen fertilizer management practices (including rates, application method, timing, and use of inhibitors), altering livestock feed mixes, and changing manure management practices. Agriculture and forest lands can also produce biomass energy feedstocks for liquid biofuels and renewable heat and power, thereby displacing emissions of fossil-derived fuels.

Climate change affects food security, natural resources, and conservation efforts. Land cover types, land uses, and crops are directly linked to climatic conditions, as are the ecosystem services they provide. The driving variables for plant growth are light, soil, water, nutrients, temperature, and CO<sub>2</sub>. Food animal production systems (including aquaculture) are dependent upon an adequate food supply, water quantity and quality, and temperature. Changing climate and weather patterns affect the geographic distribution of pests, pathogens, and weeds, as well as the frequency and severity of their occurrence. Furthermore, vulnerability of plants and animals to domestic weeds, pathogens, pests, and invasive alien species may be altered as a result of environmental conditions. Consequently, livestock and crops are affected by climatic changes. Explaining and quantifying the effects of temperature, precipitation, CO<sub>2</sub>, carbon emissions and sinks, and related environmental changes on managed and natural ecosystems requires research directed toward understanding the combined effects of these environmental factors on ecosystem responses. Innovative research strategies are required to determine how the resilience and pest responses of different ecosystems are affected by climate change. Development of improved simulation models for managed and natural ecosystems will be critical to evaluating how systems respond to climate change across a diversity of environments and ecoregions (Backlund et al., 2008).

Enhancing the sustainability of ecosystems and the essential goods and services they provide, even as climate and related environmental conditions change, is a huge challenge. Existing U.S. Department of Agriculture (USDA) programs introduce new technologies and practices for adaptation in forests, grasslands, and agricultural systems in the most efficient and least disruptive ways. Although new opportunities may be created by changes in local climates, adjustments will be challenging for many ecosystems. Mechanisms for adaptation (i.e., an adjustment in a natural or human system to a new or changing environment that exploits beneficial opportunities or moderates negative effects; National Research Council, 2010) are

critical for continued commodity production, conservation of natural resources, and food security. Application of fundamental knowledge and development of techniques and methods to enable adaptation to climate change are needed to improve the resilience of natural and managed ecosystems. Adaptation efforts currently underway must be evaluated to determine potential future adaptation measures and address the related environmental, economic, and social challenges these changes present.

USDA's strategic plan (U.S. Department of Agriculture, 2010b) addresses the challenges of climate change and the opportunities associated with addressing GHG emissions, and it further calls on the Department to lead efforts to mitigate and adapt to climate change. The plan calls for the Department to capitalize on opportunities presented by the Nation's efforts to develop markets for all goods and services and mitigate climate change. The strategic plan's second strategic goal is to ensure that our national forests and private working lands are conserved, restored, and made more resilient to climate change. To address this, the USDA Climate Change Science (CCS) Plan (U.S. Department of Agriculture, 2010a) provides a guide for the Department and its stakeholders to give clear and consistent consideration of current and potential investments in climate change science activities. The CCS plan presents an overview of the critical questions facing the Department's agencies as they relate to climate change and offers a framework for assessing priorities to ensure consistency with USDA's role in the Federal Government's broader U.S. Global Change Research Program (USGCRP) and related efforts. The CCS plan identifies important roles and responsibilities for USDA agencies—not just research, education, and extension—but across the broad spectrum of science-driven and program-delivery agencies, and areas of needs and dependencies wherein USDA agencies are reliant on other programs for cooperation.

USDA is unique in the breadth of its mission and capacity for delivering information and resources to stakeholders. Its agencies cover a broad spectrum of research, applications and technology transfer, development and public dissemination of statistics, public land management, technical assistance, protection of agriculture and natural resources, and communications and delivery. USDA agencies have engaged in weather and climate-relevant research for decades. The Department has a broad scientific base and understanding of the interactions between climate change and production/management systems; projecting the consequences of those interactions on the environment as a whole; and translating those projections into a foundation for decision-support and problem solving. USDA also has unique programs and relationships with State departments of agriculture, fish, wildlife, water resources, and environmental quality; and with universities, local governments, and industry for extending knowledge to farmers, ranchers, resource managers, and communities, and for educating future generations of scientists, policymakers, and producers.

Based on the vision expressed in the CCS plan for the USDA as a whole, the vision for the Research, Education, and Economics (REE) mission area and its partners is to have scientific discoveries and technologies delivered by USDA that empower farmers, foresters, ranchers, land owners, resource managers, policy-makers, and Federal agencies to manage the risks, challenges and opportunities of climate change, and position decision makers to reduce emissions of atmospheric GHGs and enhance carbon sequestration.

To realize this vision, REE leverages its capacity in research, education, and extension with key partners within USDA and in other Federal departments and agencies on the overarching goals and strategies to explain, adapt, mitigate, and support decisions—four goals that fully support the USDA strategic plan and the CCS plan for agriculture and forestry as the climate changes.

The ability of the REE agencies to meet the climate change research vision and four goals depend on unique core investments in climate change science, technology development, and technology and information transfer. At a broader level, REE agencies provide USDA with scientific strengths through an overarching capacity to leverage intramural research programs; extramural funding programs; and thousands of research, education, and outreach professionals in government<sup>1</sup> and universities to build consortia targeted at climate change mitigation and adaptation at local to global scales. Many connections exist with other federal departments engaged in local, regional, national, and international climate change mitigation and adaptation research through the USGCRP. These include, for example, the Conservation Effects Assessment Program, landscape-based initiatives such as the National Science Foundation's National Ecological Observatory Network (NEON) and its Long Term Ecological Research (LTER) network, the United States Group on Earth Observations, and other interagency climate change coordination groups and resource centers in the Agricultural Research Service (ARS), Economic Research Service (ERS), Forest Service, Farm Service Agency, National Agricultural Statistics Service (NASS), National Institute on Food and Agriculture (NIFA), Natural Resources Conservation Service (NRCS), and Foreign Agriculture Service (FAS). In addition, ARS is examining the proposed coordination of its national network of experimental watersheds and rangelands into a long-term agro-ecosystem research network modeled on the National Science Foundation's LTER network to leverage extramural funding and teams of government, university, and private-sector partners. Leveraging interagency and interdepartmental resources will allow USDA and its partner agencies to generate change for the agricultural and forestry sectors that would not be possible from independent efforts.

An important consideration in meeting the four goals is the overall coordination of climate change science and outreach activities within the Department, where many agencies (not just those in REE) have relevant programs and interests. The USDA Climate Change Program Office (CCPO), a unit with the USDA Office of the Chief Economist, functions as the Department-wide coordinator of agriculture, rural, and forestry-related global change program and policy issues facing USDA. The CCPO ensures that USDA is a source of objective, analytical assessments of the effects of climate change and proposed response strategies. It also serves as USDA's focal point for climate change issues and is responsible for coordinating activities with other Federal agencies, interacting with the legislative branch on climate change issues affecting agriculture and forestry, and representing USDA on U.S. delegations to international climate change discussions. The CCPO convenes the Department's Global Change Task Force, which is composed of representatives of the REE agencies and those in other USDA mission areas, including the farm and foreign agricultural services, marketing and regulatory programs, natural resources and environment, rural development, and the Forest Service. The CCPO director serves as USDA's principal point of contact for interdepartmental groups such as

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<sup>1</sup> Particularly with agencies that have significant research and development efforts in climate change such as the National Science Foundation, Environmental Protection Agency, National Aeronautics and Space Administration, Department of Energy, National Oceanic and Atmospheric Administration, and Department of Interior.

the USGCRP; as a first point of contact for many non-USDA agencies, nongovernmental organizations, and other stakeholders that have interest in USDA climate change programs; coordinates USDA's contributions to the National Climate Assessment report to Congress and inventories on agricultural GHG emissions; organizes special working groups to prepare white papers, policy analyses, and other documents for consideration by Administration officials; works to include USDA and USDA interests in international agreements and documents such as the Intergovernmental Panel on Climate Change; and serves as a general source of information on agriculture and climate change within and outside USDA. Through the CCPO and Global Change Task Force, agencies and offices throughout USDA are kept informed of REE research progress on climate change topics and made aware of their programmatic needs.

In coming years, REE will continue to invest its infrastructure assets, research capacity, and partnerships in relevant research, information systems, and dissemination on a wide range of topics and issues such as crop, forestry, and livestock genomics/genetics; soil quality and management; watershed and rangeland management; and crop, forest, range, livestock, and aquatic management systems. An ultimate goal of decision support keeps USDA's focus on research with practical applications and tangible results to mitigate GHG emissions and adapt agricultural and forest ecosystems to climate and other environmental changes. REE will educate stakeholders, solve challenges in GHG mitigation, and adapt agricultural and forest ecosystems to a changing environment.

The outcomes of the four main goals of this plan—explain, adapt, mitigate, and support decisions—will keep the supply, quality, safety, and value of agricultural and forestry products apace with population growth, avoid a proportional increase in GHG emissions, prepare the Nation's farmers and foresters with appropriate adaptation resources, and offer solutions for emissions in communities and other sectors of the economy. In the details below, the role of REE agencies is specified, with key partners noted.

## **Current Research Challenges and Proposed Research**

### **Strategy 1: Explain the Processes Driving the Direct and Indirect Effects of Climate Change on Natural and Managed Ecosystems, Including Feedbacks to the Climate System**

Successful adaptation and GHG mitigation strategies and policies rest on a foundation of reliable predictions of how the processes and components of agricultural and climate systems respond to natural and human-induced changes in environmental conditions, including agricultural and resource management. USDA research leads to scientific explanations of causes and effects of climate change and the capability to estimate effects on natural and managed ecosystems, including feedbacks to the climate system. This explanatory power is essential to predictive capabilities and decision-support. Information on the genotypic and phenotypic variation among and within crop, livestock, and pest species is an essential aspect of predicting how climate change and related environmental factors may affect agricultural systems. Fundamental studies of plant water and nutrient use efficiency, as well as nutrient formulations and management, are necessary to determine ways to sustain or increase yields with less water and fertilizer. Research required includes experiments and biologically based simulation models to quantify the combined effects of changing precipitation and water availability, increasing temperature, and

increasing atmospheric CO<sub>2</sub> and tropospheric ozone concentrations on agricultural and forest productivity, the occurrence and impact of pests, pathogens, invasive species, and ecosystem services. Carbon is the basis of all living organisms, and its storage and cycling in the soil is directly tied to soil health and productivity. Thus, carbon and CO<sub>2</sub> are key components of all important goods and services. Combined with extensive research on temperature, drought, and other abiotic stresses on crops and livestock, a better understanding of how CO<sub>2</sub> affects growth and development of crops and their pests, and the cascading effects on carbon and nitrogen cycling is needed to understand the effects of the entire suite of climate change factors on ecosystem functions and cycles, including the global carbon and nitrogen cycles.

Current USDA Science:

- A national network of instrumented watersheds, ranges, and experimental forests, ranging in size from dozens to millions of hectares, is providing extensive observational and experimental data, some reaching back decades. A national grid of 300,000 permanent sample plots is deployed across the entire U.S. forest landscape, along with the nationwide Cropland Data Layer (in geographic information system format), an area sampling grid, and farm operator list sampling frames. These assets permit REE scientists and their partners to evaluate status and trends in agricultural and forestry resources, to provide a foundation for baseline resource conditions, and to test resource conservation practices, carbon sequestration, and adaptation approaches and their impacts. ARS is implementing plans to organize its watersheds and rangelands into a long-term agro-ecosystem research network that offers opportunities to partner with other funding agencies, universities, and the private sector. USDA scientists partner with university researchers to conduct field studies of atmospheric enrichment of CO<sub>2</sub> and tropospheric ozone, temperature, and their interactions with other environmental factors and management decisions on plant growth and yield in croplands, grazing lands, and forests.
- Nationally coordinated research in REE agencies and their partners permits 1) the development of large-scale examinations of the responses of agricultural and forestry systems (including pests) to anticipated climate change; 2) evaluations of germplasm and identification of genetic variation that will respond positively to climate change or provide crop/livestock resistance to pests emerging under changing conditions; and 3) identification and development of scalable methodologies for assessing potential effects and adaptation strategies for agriculture and forests to climate change.
- Research by USDA scientists and their collaborators is helping determine how different nutrient formulations, crop genetics, rhizosphere processes, and management techniques (including organic, conservation, and integrated crop-livestock systems) affect the rates and kinds of transformations of nutrients, emissions of GHGs, carbon sequestration, and water use.
- Research is elucidating the potential interactions between sequestered carbon and emission rates of other GHGs in croplands and grazing lands; and the effects of feeds and livestock management on methane emissions from livestock and their wastes.

### Anticipated Outcomes:

- Projections of crop, livestock, forestry, range, and aquaculture yields at multiple scales under different current and projected climate scenarios (NIFA).
- Scalable species-specific geospatial information to support monitoring and assessing the impact of climate change on the Nation's managed lands (ARS and NASS in partnership with the Forest Service).
- Data and conceptual models indicating how climate change affects 1) crop, timber, and forage quality; 2) the interacting effects of elevated CO<sub>2</sub>, ozone, precipitation, and temperature on production systems including nitrogen requirements, yield, and quality responses of wheat, soybean, sorghum, corn, rice, forages, and forest species; and 3) effects of elevated CO<sub>2</sub> on plant responses to soil water deficits and air moisture vapor pressure deficits (ARS in partnership with the Forest Service).
- Projections of the distribution, incidence, and severity of outbreaks of pests, pathogens, and weeds in crop, range, and forest ecosystems, on the basis of data for responses of pest and host species to changes in climate, weather variability, CO<sub>2</sub> concentration, and other related environmental variables (ARS in partnership with NIFA, Animal and Plant Health Inspection Service [APHIS], and the Forest Service). In addition, land-based infrastructure for research, environmental management testing, and education, will enable us to understand and forecast the nation's capacity to provide agricultural commodities and other ecosystem goods and services under ever-changing environmental and resource-use conditions.

### **Strategy 2: Develop Knowledge and Tools to Enable Adaptation of Agriculture and Forestry to Climate Change, Including Improving the Resilience of Natural and Managed Ecosystems**

Adaptation to climate change is a strategic necessity for REE, USDA, and the Federal government as a whole. In response to Executive Order 13514, "Federal Leadership in Environmental, Energy, and Economic Performance," the White House's Climate Change Adaptation Interagency Task Force issued implementation instructions (Council on Environmental Quality, 2011a) for Federal agency climate change adaptation planning. The instructions say that "each agency will identify aspects of climate change that are likely to impact the agency's ability to achieve its mission and sustain its operations and respond strategically. Adaptation planning will help an agency reduce the negative effects and take advantage of new opportunities that climate change may bring. Integration of climate change adaptation planning into the operations, policies, and programs of the Federal Government will ensure that resources are invested wisely and that Federal services and operations remain effective in current and future climate conditions." Research conducted by REE agencies and their partners ensures that USDA can achieve climate change adaptation needed for the Nation's agricultural operations, policies, and programs.

By first quantifying and explaining the effects of temperature, precipitation, and CO<sub>2</sub> changes on managed and natural ecosystems, USDA provides a foundation for projecting and then managing the combined effects of these environmental factors on ecosystem responses. Knowledge of mechanisms for adaptation are critical for continued commodity production, conservation of

natural resources, food security, and the well-being of the agricultural/forestry sector and rural communities. New genotypes and phenotypes of crops, livestock, and trees will be identified and developed through breeding programs to ensure agricultural and forest sustainability despite changing climate, weather variability and extremes, and atmospheric composition. Production and resource management options are being developed and tested at field scales to ensure that the potential offered by current and improved genotypes is ultimately realized. Predictive capabilities, including simulation models to quantify the combined effects of changing precipitation and water availability, increasing temperature and atmospheric CO<sub>2</sub> concentration on productivity and system services, are being developed to increase the resiliency of agricultural and forestry systems via the use of models as decision support tools. Development of improved simulation models for managed and natural ecosystems will be used to evaluate how systems respond to climate change. Simulation models will include integrated hydrology, soil properties, land use, nutrient cycling, plant productivity, ecology (including interactions with arthropod pests, pathogens, weeds, and invasive species), product quality, management practices, and their effects on ecosystem goods and services. Models that include economic and social feedback mechanisms are essential for identifying the range of potential outcomes.

The Interagency Climate Change Adaptation Task Force report (Council on Environmental Quality, 2011b) also calls for the establishment of regional climate change consortia to coordinate research, improve stakeholder access to climate services, facilitate adaptation planning, and contribute to the national climate assessment. REE agencies will play an important role in developing these consortia and in disseminating climate information to land managers whose operations rely on timely, accurate scientific information.

Current USDA Science:

- National germplasm collection and storage systems for crops, livestock, and trees are the source of genetic traits for breeding new varieties and breeds that are resistant to abiotic and biotic stresses, or to conserve species under threat; for example, through the National Center for Genetic Resources Preservation or the National Plant Germplasm System, or both.
- Intramural and sponsored agricultural research and development on productivity in crops and livestock provides a basis for developing research investment strategies to address yield changes, environmental stresses, and resource constraints.
- Research on genomics, genetics, and breeding is leading to crop, livestock, and tree varieties that can withstand climate change, including weather variability and extremes, changing concentrations of CO<sub>2</sub>, ozone, and other gases, and climate change–induced alterations in interactions of host plants and animals with pests, pathogens, vectors, and weeds.
- Scientific, statistical, and remote sensing–based technological capacity enables USDA to develop and disseminate large-scale geospatial, land use–specific, scalable information to monitor and assess the effects of climate change on the Nation’s agricultural lands and forest ecosystems.
- A system of overseas laboratories (in Argentina, Australia, China, France, and Panama) offers the ability to conduct global research on exotic pests, pathogens, vectors, and biological control agents.
- Extensive expertise in pest risk assessment and risk management leads to better surveillance and management strategies for pests, pathogens, weeds, vectors, and invasive species of all



types that affect crop, livestock, rangeland, and forest systems that are being influenced by changing climate and weather patterns.

Anticipated Outcomes:

- Science-based strategies and practices that enable management of crop, grazing, and forest lands given the challenges associated with drought, heat stress, moisture stress, atmospheric deposition, ozone, and changes in disease and pest prevalence (ARS in partnership with the Forest Service).
- Projections of crop, livestock, forestry, range, and aquaculture yields at multiple scales under different current and projected climate, management, and policy scenarios or options (ARS, ERS, and NIFA in partnership with the Forest Service).
- New genotypes and phenotypes of crops, livestock, and trees are expected to be developed that are resilient to the stresses induced or exacerbated by climate change, by increased weather extremes and variability, and by changing composition of the atmosphere. New techniques and farming practices that allow for greater adaptability to changing climate and environmental conditions are expected (ARS and NIFA in partnership with the Forest Service).
- New risk assessment and planning processes are expected for projecting pests, pathogens, invasive species, and abiotic stresses in croplands, forests, and rangelands (ARS in partnership with APHIS and the Forest Service).
- Projections of the outcomes from producer choices for adapting to climate change, relative to crop types, farm sizes, agronomic practices, ownership types, adoption of technology, and agricultural markets are expected (ARS and ERS in partnership with the Forest Service).
- Large-scale geospatial, crop-specific information is expected to help monitor and assess the effects of climate change on the Nation's agricultural lands (ARS and NASS in partnership with the Forest Service).

**Strategy 3: Develop Knowledge and Tools to Help Mitigate Atmospheric GHG Emissions through Reductions in Gross GHG Emissions and Increases in Carbon Sequestration in Agriculture, Forestry, Grasslands, and Other Managed Lands**

USDA research can ensure that agriculture and forestry will play significant roles in reducing atmospheric GHG concentrations through carbon storage and reduced emissions. Farm, ranch, and forest land managers can increase sequestration by adjusting land uses and production systems; this would be highly cost-effective relative to mitigation options in other sectors and can potentially return value to the agricultural/forestry sector, rural communities, and society as a whole. Given the high global warming potentials of N<sub>2</sub>O and CH<sub>4</sub>, management of these emissions, particularly from animal production and nutrient management, is of particular importance. New data series that are timely, accurate, and unbiased are critical to the effectiveness and efficiency of carbon offset markets or income potential.

Current USDA Science:

- Nationally coordinated measurement and monitoring and modeling of carbon sequestration and GHG emissions (e.g., GRACEnet and Animal GRACEnet, the Consortium for

Agricultural and Soil Mitigation of Greenhouse Gases (CASMGs), Forest Inventory and Analysis (FIA), National Resources Inventory (NRI), Forest Service Soil Productivity Network) to enable annual and periodic reports and provide projections of carbon storage and GHG emissions on forest, range, and agricultural lands.

- Broad-based research on input/output production efficiencies, including genetic improvement of crops, livestock, and trees leading to lowered net GHG emissions per unit of commodity production.
- Sustained research, development, and use of alternatives to petroleum-based pesticides, including methyl bromide (a gas used in soil-borne pest management and phytosanitary treatments and which depletes stratospheric ozone) are expected to help reduce the carbon footprint of agricultural systems.

Anticipated Outcomes:

- Economically viable strategies and technologies for reducing GHG emissions and increasing carbon sequestration considering all relevant fluxes while improving confidence estimates (ERS).
- Improved agricultural practices and management systems that influence CO<sub>2</sub>, N<sub>2</sub>O, and CH<sub>4</sub> emissions, soil carbon-nitrogen interactions at multiple scales, and carbon sequestration in crops, livestock, and on grazing lands (ARS).
- Improved crop, livestock, and tree genotypes, management systems, and guidance to minimize emissions and enhance carbon sequestration on agriculture and forest lands (ARS in partnership with the Forest Service).
- Technologies and information for reducing GHG intensity (net emissions per unit of commodity produced) in a wide variety of agricultural production and forest management systems worldwide, including outcomes from REE's leadership in the Global Research Alliance on Agricultural Greenhouse Gases (ARS, ERS, and NIFA in partnership with APHIS, the Forest Service, and the Natural Resources Conservation Service).

**Strategy 4: Support Decisions, Including Policymaking, Via Information and Techniques USDA Science Will Provide to Government Agencies, Stakeholders and Collaborators**

The scientific research and many ongoing core information programs produced and funded by USDA have been used for many years to address a range of questions from detecting climate change trends and effects to the use of remote sensing, ground-based observations, and related analyses in resource management applications. To maximize the effectiveness of this basic research, results must also be applied by agencies administering conservation programs, directly managing lands, providing management advice to private land holders, or carrying out regulation. USDA has strong relations and interactions with internal and external partners and stakeholders and develops resources to support public discussion and planning, adaptive management, and policymaking. USDA encourages the development of new methods, models, decision methodologies, and other resources that facilitate economic analysis and decision-making under conditions of uncertainty, and integration and interpretation of information from the natural and social sciences in relevant decision contexts. This effort includes supporting and improving existing models and decision-support mechanisms. Development of decision-support

resources cannot be isolated in a single agency or office within USDA. Rather, success depends on developing strategies for integrating knowledge from throughout the Department and making it available within needed time frames in usable formats to internal and external stakeholders. USDA's strategy to better understand human environmental interactions recognizes the need for basic research in the natural sciences and the human dimensions of global change for producing decision-support resources. Education, outreach, and new science-based information systems are needed to achieve literacy and action to mitigate and adapt to climate change. USDA provides leadership and works with its stakeholders and partners to support scientific and educational activities and to provide extension professionals and the public with the capacity to disseminate the information necessary to develop responses to climate change, and to encourage the development of the next generation of agricultural professionals.

#### Current USDA Science:

- Direct linkage of the biophysical and social science research communities to education, outreach, and technology transfer professionals ensures that new knowledge is translated to useful products and given to the public and private sectors so that they can make better decisions.
- Regularly scheduled reports of farm and forest production enable scientists to project from the current growing season to a decade in the future, taking into consideration commodities, trade, and aggregate indicators of the sector, such as farm income and food prices.
- The Agricultural Resource Management Survey provides data to help analyze the effects of climate policies on the farm sector and the potential for farmers to provide offsets, including statistics on the costs of energy inputs, as well as the costs and adoption rates of farm practices related to climate change such as conservation tillage and methane digesters.
- Agricultural sector models are being developed with detailed regional information on environmental consequences, including GHG emissions that cover global markets and linkages with the nonagricultural economy. These models will be used to answer a wide range of questions that encompass the effects of biofuel expansion, U.S. conservation programs, and environmental policies such as regulation of confined animal feeding operations.
- The every-5-year Census of Agriculture, annual county estimates, and prices received and paid series of data provide basic agricultural and rural statistics, offering essential baseline data at multiple levels that are used in many climate-based socioeconomic models, land use and land cover change models, and as proxies for science-based statistics on GHG emissions, carbon inventories, and sequestration potential.
- The annual NASS Cropland Data Layer and other large-scale remote sensing applications are a focal point throughout government, academia, and the private sector for use in geospatial applications at multiple levels in precise analyses of environmentally affected land use and land cover change.

#### Anticipated Outcomes:

- Annual input to the Environmental Protection Agency's official U.S. inventory, and estimates and changes of GHG emissions, sinks, and carbon stored in soils, crops, forests, and rangelands (ARS and ERS in partnership with the Forest Service).

- Projections of carbon storage outcomes of climate, management, economic, and policy scenarios at scales from field to Nation (ERS in partnership with the Forest Service).
- With Federal partners, work toward establishing and implementing a Federal agency-wide National Climate Service that includes climate extension services and decision support systems development (ARS and NIFA in partnership with the Forest Service and the World Agricultural Outlook Board).
- Resources, leadership, and guidance for the development of extension-oriented communities of practice through the eXtension system focusing on climate and forestry and sustainable living education (NIFA in partnership with the Forest Service and the World Agricultural Outlook Board).

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