3.2.3 IMPROVED MEASUREMENT AND MONITORING
3.2.3.1 TERRESTRIAL SENSORS, MEASUREMENTS, AND MODELING

Technology Description

Agricultural lands (cropland, pasture, rangeland) represent potentially large and cost-effective sinks for atmospheric carbon, if management technologies can be applied in the right place at the right time. Management to increase carbon sequestration requires the development of more sophisticated, lower-cost measurement systems and models for integrating multiple data sources into a decision-making context.

System Concepts

- In the past, management of soil carbon and greenhouse gas (GHG) emissions has not been a primary management goal in agriculture. Consequently, efforts to develop rigorous quantification systems at multiple scales (local, regional national) are relatively recent, but are rapidly developing.
- Methods exist to accurately and precisely measure soil carbon and GHG concentrations and fluxes. However, most conventional methods were developed for local measurements. Plot and field applications and numerous samples must be analyzed for accurate and precise values.
- Models (particularly computer simulations) of soil carbon and GHG dynamics exist and several are in widespread use and have been extensively tested against research data. Their development and use in inventories, policy assessment, and decision-support environments is only recent.
- Emergence of new sensing technologies (i.e. laser, infrared, multispectral video) and computing power capable of handling large amounts of information has spawned a new generation of instruments, databases, and computer models.
- There is a rich collection of resource data on factors determining soil carbon and GHG dynamics in croplands, e.g., survey data on management practices, crop areas and yields, soil maps, land cover, and irrigation. Much of the data is spatially referenced and can be used to drive stimulation models and interpolate/extrapolate measurements. Similar data exists for grazing lands, with the exception of type, distribution, and extent of different management practices for which information is currently sparse.

Representative Technologies

- Instruments to measure GHG fluxes among soils, plants, animals, and the atmosphere.
- Models to integrate spatial and temporal variability into a decision context.
- Easily accessible, interactive distribution systems of quantification technologies that integrate measurement and modeling approaches.

Technology Status/Applications

- New sensors, instruments, measurement systems, models, and distribution systems are emerging, but integrated systems of information collection, retrieval, management, manipulation, and processing to aid decision making in complex and diverse agricultural environments have yet to be developed.
- Integrated information management and the physical sciences now have the capacity to provide vastly improved information to land managers and policy makers to improve the amount of carbon stored in grazing land soils.

Current Research, Development, and Demonstration

RD&D Goals

- Develop a new generation of sensors and instruments to measure GHGs and their fluxes in situ across a wide variety of agricultural ecosystems.
- Develop cost-effective soil carbon probes for in situ measurement of soil carbon content (as opposed to fluxes) that can be made both before and after implementation of management changes to validate impacts on sequestration.
- Determine time and cost-efficient sampling and monitoring designs to support national inventories and project level GHG mitigation activities.
- Combine measurement technologies and ecological process models to make reliable predictions (and verify them) regarding the impact of management on GHG dynamics.
- Integrate near real-time climate information into process models as a driver.

- Distribute site-specific information to farmers, ranchers, and technical assistance providers to aid in making more realistic decisions.

RD&D Challenges

- High spatial and temporal variability results in very complex situations that must be measured and modeled. Data sources will be multisource and large.
- Successful implementation will require substantial improvements in the ability of field staff and land managers (farmers and ranchers) to use complex information.

Recent Progress

- Laser-induced breakdown spectroscopy instrument to measure soil carbon in situ for less than 10% of the lab costs of other methods with comparable reliability.
- Mid-range infrared spectroscopy to measure soil carbon and forms.
- Near-infrared spectroscopy technology and Nutritional Balancer software to accurately predict livestock diet quality based on fecal analysis.
- Biophysical models have been developed to integrate spatial and temporal variability in soils into a predictive framework for making estimates of changes in soil carbon in response to climate and management.
- Satellite and low-altitude remote-sensing technologies have been developed that can quantify cropland and grassland features at a spatial resolution of less than 0.5 m^2.
- Internet distributed site-specific information systems that integrate near real-time weather predictions, land condition, and land-cover classes have been developed. Such tools provide ready access to information used in developing decision tools and in dynamic models as inputs.
- Decision-support systems are being developed that can integrate information to evaluate implications of various management decisions.

Commercialization and Deployment Activities

- Markets in precision agriculture and decision-support consultation are potentially large.
- Technical basis of instruments, models, and information systems is proven, but their systematic deployment to solve complex problems remains unexplored.

3.2.3.2 MEASURING AND MONITORING SYSTEMS FOR FORESTS

Technology Description

Forest systems provide a significant carbon sink and can contribute to GHG emissions. To mitigate GHG effects, advanced technology is needed to measure and monitor forest and wood product processes, pools, and fluxes to better manage these systems to reduce and mitigate emissions, and to enhance carbon sinks. Measurement systems should be integrated using a multitiered approach combining national inventories, remote sensing, land-based measurements, and intensive monitoring on experimental sites.

System Concepts

- Forest GHG inventory and measurement systems cover broad temporal and spatial scales, include various methods and technologies, and rely on direct measurements at the site and remote scales, as well as interpolation and expansion of observations to nonmeasureable pools and fluxes. No single inventory system provides the comprehensive coverage across all scales.
- An advanced measurement and monitoring system would combine national inventories, remote-sensing data, regional and site studies and measurements, experimental data, and modeling capabilities into a comprehensive observational and analysis system.

Representative Technologies

- The USDA Forest Service's Forest Inventory and Analysis Program and the Natural Resources Conservation Services' National Resources Inventory provide the basis for a national carbon inventory and annual changes in carbon pools for forest, pastures, and croplands.
- Wide range of technology such as global positioning systems, satellite and aircraft based remote sensing, in situ electrical, magnetic, optical, chemical, and biological sensors, and scientific instruments.

Technology Status/Applications

- LIDAR and RADAR remote-sensing methods are being developed and tested for 3-D imaging of forest structure. Additional work is needed to integrate remote and land-based measurements.
- Low-cost, portable, real-time measurement systems are not available for soil monitoring and other in situ measurements.

Current Research, Development, and Demonstration

RD&D Goals

- Technology advances are needed in (1) enhanced remote-sensing data collection and analysis, (2) expansions and enhancements of extensive inventories systems for large-scale, landscape, and integrated resource measurements, (3) in situ instrumentation and monitoring systems for intensive monitoring, (4) specialized measurement and characterization systems for soils, and (5) integrating measurements and data.
- Reduce uncertainty associated with the national carbon inventory by improving coverage of national inventories and analyses of changes.
- Develop understanding of underlying processes of biological and ecological processes in order to develop improved monitoring systems and use systems to validate models for mitigation actions.
- Improve and develop low-cost, portable, real-time sensors and measuring systems for in situ measurements.
- Provide integration and systems design of remote sensing and ground-based carbon pool and GHG fluxes measurements technology using multitiered system.

RD&D Challenges

- National inventory systems were not designed for carbon and other GHG measurements and have not been adequately supported to develop complete wall-to-wall, comprehensive inventories of carbon pools and fluxes among the pools and atmosphere.
- There is little understanding of forest soil processes in the storage and allocation of carbon. This information is paramount for the development of management systems and practices that enhance carbon sequestration.
- The broad range of required scales, cover types, and ecosystems will require the development of (1) remote sensing integrated with other measurements at various levels of coverage, duration, and intensity, and (2) low-cost, robust measurement systems that can effectively be used at different scales. Sites covered need to

be expanded as part of extensive monitoring and intensive measurement systems.

- A great wealth of information and data will be acquired by enhanced measurement and monitoring systems. Advances are needed in the technology to manage, process, translate, analyze, and transform this information into predictive and decision-making tools.
- Develop measuring and monitoring systems for carbon pools in wood products in use and in landfills.

RD&D Activities

- Efforts are underway to improve carbon inventory systems and reduce the uncertainty of our national inventory.
- Improvements are being made in remote sensing, senor, instrumentation, and measuring system technology through Federal, university, and private collaboration.
- Current technology needs to be more fully deployed; and new, innovative technology should be piloted and demonstrated to accelerate deployment.

Recent Progress

- The USDA Forest Inventory and Analysis Program assesses the U.S. forest structure and condition and is the basis for our nation's carbon inventory in concert with information provided by the National Resource Inventory. Periodic national carbon inventories have been produced using this data.
- The AmeriFlux network is being completed, which will improve the understanding of carbon pools and fluxes in large-scale, long-term monitoring areas and intensive experimental sites.
- Research programs are in place that can (1) provide inventory of carbon stocks, (2) understand and quantify biological processes, (3) model and predict climate impacts and management strategies, and (4) develop effective, low-cost management systems.
- Partnerships have developed among government, university, and private research organizations to improve greenhouse gas measurements.

Commercialization and Deployment Activities

- Global positioning systems are currently in use and can provide geo-references for carbon measurements.
- Current technology is not fully deployed; efforts are needed to demonstrate and increase the efficiency of such technologies.
- Specialized remote sensing technology is being developed and will be deployed in the near term for the measurement of greenhouse gas emissions and carbon stocks.
- A comprehensive, integrated, multiple-tier measuring and monitoring system needs to be fully developed and deployed.

Market Context

- Improved technology for carbon measurements can provide security in credit trading.
- Enhanced measurement systems can provide input for the optimal design, deployment, and management of forest and wood product systems that will provide additional carbon sequestered and ancillary benefits.