## 5.4 MM FOR TERRESTRIAL CARBON SEQUESTRATION

### Technology Description

**Introduction**

Terrestrial ecosystems (forests, pastures, grasslands, croplands, etc.) offer significant near-term and low-cost options to sequester carbon. Of course, such lands also can contribute to emissions through normal operations (e.g., tillage practices, fertilizer use, fires, and pests). Measuring and monitoring (MM) technologies must address both aspects so that a full accounting of changes in carbon stocks and fluxes of $CO_2$ or other GHG can be determined.

**System Concepts**

- A hierarchical system will integrate carbon sequestration (CS) measurements of different system components (e.g., soils, ecosystems) and for a range of scales (e.g., plot, landscape, regional) to provide a net accounting of $CO_2$ (and other GHG) inventories, emissions, and sinks.
- Routine reporting and measurement systems must be complemented with intensive monitoring on multiscale experimental sites to ensure validation of the methods.
- A system for analysis of the large quantities of data must be developed, as data alone will be insufficient to assess changes in stock, emissions, and sinks.

**Representative Technologies**

- The USDA Forest Service's Forest Inventory and Analysis Program and the Natural Resources Conservation Services' National Resources Inventory provide the underlying data for estimating a national carbon inventory and annual changes in carbon pools for forest, pastures, and croplands.
- Airborne and space-based platforms used to remotely sense land use/cover changes and biomass (e.g., LAI, soil moisture) are in place and are undergoing use and further enhancements and validation via land-based studies.
- Eddy covariance flux towers for area-scale $CO_2$ flux measurements.
- Laser-induced breakdown spectroscopy for soil carbon analysis for point measurement ($<mm^2$) and neutron-scattering methods for volumetric measurement ($\sim 1\ m^3$).
- A variety of models and decision-support tools for converting observations to information that can be used to implement greenhouse gas stabilization practices are being developed.

**Technology Status and Applications**

- Imaging, LIDAR, and RADAR remote sensing methods are being developed and tested for 3-D imaging of forest structure. Quantification is lacking and directly coupled, land-based measurements are not able to be easily integrated with remote sensing data.
- Laboratory-based LIBS analysis is calibrated and in testing; rapid, in situ soil carbon measurement systems are under development but not ready for field implementation.
- Eddy covariance flux measurement systems are being developed, but are not ready for deployment with all landscapes and would be difficult to implement at high spatial density.
- Methods and models to process land inventory data for estimating carbon changes and attributing changes to human-caused and natural factors are being revised as more accurate data are provided by recent technologies.

### Current Research, Development, and Demonstration

**RD&D Goals**

- Provide integrated, hierarchical system of ground-based and remote sensing for carbon pools and $CO_2$ and other GHG flux measurements.
- Reduce uncertainty on regional-to-country scale inventories of carbon stocks.
- Develop low-cost, portable, rapid analysis systems for in situ soil carbon measurements.
- Develop standard estimates that relate management practices to net changes in emissions/sinks over time (e.g., life cycle of wood products, changes in agricultural crop rotations, energy use in ecosystem management, etc.).

**RD&D Challenges**

- Emission/sink factors for management practices must be based on a more complete understanding and quantification of ecosystem carbon allocation and storage processes.

- 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.
- For such data collection methods to be of value, advanced data distribution, analysis, and simulation tools will be needed for scale-up of site-specific changes in carbon stocks to regional and global estimates. Sites covered need to be expanded as part of extensive monitoring and intensive measurement systems.

**RD&D Activities**

- The AmeriFlux network is being completed. It will improve our understanding of carbon pools and fluxes in large-scale, long-term monitoring areas and intensive experimental sites.
- Terrestrial carbon process R&D and technology development through the North American Carbon Program (NACP) will result in an understanding of mechanisms of carbon sequestration, and will contribute to the development of standard estimates for applications of carbon management practices.
- Technology for in situ sensors is supported.
- Development of remote sensing platforms and ground-based validation of carbon stocks is underway and should lead to national-scale methods.

**Recent Progress**

- USDA FIA and NRCS program provide information to assess the structure and condition of U.S. forests, croplands, pastures, and grasslands that is then converted to state, regional, and national carbon inventories.
- Prototype soil carbon analysis systems have been developed and are undergoing preliminary field testing.
- Satellite and low-altitude remote sensing technologies have been developed that can quantify agricultural land features at spatial resolution of approximately 0.5 $m^2$.
- Prototype versions of Web-based tools for estimating carbon budgets for regions.
- Increased accuracy of carbon sequestration estimates related to land management and full carbon accounting.

**Commercialization and Deployment Activities**

- Forest inventory measurement methods are being deployed at the project scale within the United States and other countries that will allow assessment of costs, utility, and accuracy.
- Tillage and land conservative practices are ongoing and offer test-beds for ground-based and remote sensing methods, as well as verification of rules of thumb for emissions factors.
- Opportunities for software development and support; and for development of models to support reporting under the 1605(b) program.