Appendix A. Reference and Alternative Mitigation Scenarios

The reference and alternative mitigation scenarios will be designed to deliver results on the assessment components. (See chapter 1 for interpretation of the components and key concepts.) In essence, the components of the assessment required by section 712 of the Energy Independence and Security Act of 2007 (EISA) (U.S. Congress, 2007) will be satisfied by an evaluation of current carbon inventories, as well as potential carbon-sequestration capacity and greenhouse-gas (GHG) emission reductions from mitigation activities and strategies in ecosystems under a range of climate scenarios. The three overarching scenarios will be from the Intergovernmental Panel on Climate Change (IPCC) "Special Report on Emission Scenarios" (SRES)—A1B, A2, and B1 (Nakicenovic and others, 2000). The three IPCC scenarios are the socioeconomic storylines that will be used to guide the development of specific mitigation scenarios for this assessment. They are broad in scope and consistent with the IPCC SRES used in the U.S. Department of Agriculture (USDA) U.S. Forest Service's (USFS) 2010 Forest and Rangeland Renewable Resources Planning Act (RPA) assessment (U.S. Department of Agriculture, U.S. Forest Service, 2010). The IPCC SRES storylines are derived from assumptions on global-level driving forces and need to be downscaled to the national and regional level. The role of the storylines is to push experts to think beyond present conditions and the current range of thinking.

For this assessment, reference and alternative scenarios for mitigation will be developed within each of the IPCC storylines. Reference scenario (R) and alternative mitigation scenarios in each assessment unit are developed for various socioeconomic storylines and climate scenarios. Alternative mitigation scenarios are designed to enhance carbon sequestration and reduce GHG emissions from land-management change (scenario M), land-use and land-cover change (scenario L), or both (scenario ML).

This appendix provides details on the national and regional processes to construct reference and alternative scenarios. At the national level, mitigation activities—such as land-use and land-cover (LULC) change and land-management changes—are selected for national assessment from a compilation of candidate mitigation activities. They are prioritized for national importance based on the existing knowledge of carbon-sequestration capacity, quantity of land suitable for the activity, and consulting agency priority. Ultimate inclusion of a mitigation activity in the assessment is determined by data availability and modeling capabilities. Also, national-level consultation will be used to develop a national set of storylines consistent with IPCC SRES and to establish guidelines for scenario construction to ensure consistency across ecoregion assessments. At the ecoregion level, reference scenarios (R) of LULC and land management are projected for each of the storylines within the confines of the national interpretation. For each ecoregion, mitigation activities will be evaluated for the potential to maximize carbon sequestration and minimize GHG emissions; evaluations will use published studies, regional expertise, and spreadsheet calculations. Mitigation scenarios are portfolios of management activities and LULC changes described in terms of amounts of change and timing of implementation. In accordance with national guidelines, alternative mitigation scenarios will be constructed to enhance carbon sequestration. Further elaboration of mitigation-activity selection, interpretation of the IPCC storylines for the reference and mitigation scenarios, and scenario construction follows. The last section provides a summary of the national and regional consultation process.

A.1. National Selection of Mitigation Activities

The selection of mitigation activities for the national assessment involves prioritization of mitigation activities and identification of the relevant national datasets. The assessment addresses two types of mitigation activities that ecologically sequester carbon or mitigate GHG emissions in ecosystems: LULC change and land-management change. LULC change is described in terms of changes between thematic LULC classes (section 3.2 of the main document), and land management occurs within the confines of a LULC class. LULC changes for increasing carbon sequestration include afforestation (conversions from pasture and croplands into forested land classes), mine-land reclamation, and wetland restoration or construction (transitions into the wetland classes). LULC changes to reduce GHG emissions may include the reduction of deforestation and the reduction of rice cultivation. Management activities on croplands may include conservation tillage, more efficient fertilization application, and crop rotations. On forest lands, management pertains to forest management and timber harvesting. All these mitigation activities affect GHG fluxes from aquatic systems via effects on erosion and nutrient loads.

Candidate mitigation activities have been compiled from the literature (for example, Lewandrowski and others, 2004; Murray and others, 2005; Eggleston and others, 2006) and underwent preliminary preparation and review at a policy workshop that was conducted by the Center for Climate Strategies and convened at the U.S. Geological Survey (USGS) headquarters in Reston, Va., December 1–2, 2009. A catalog of mitigation activities was distributed in advance and participants provided feedback. Criteria to prioritize mitigation activities for national assessment may include the primary considerations for ecological carbon-sequestration capacity:

- Sequestration capacity per hectare of mitigation activity
- Hectares of suitable lands for mitigation activity change to identify applicable upper bounds on mitigation activity change
- Time-effectiveness of sequestration to address how quickly the mitigation activity provides climate-change mitigation and duration of the effect of the mitigation activity on sequestration rate (for example, five decades for management activities affecting forest

and soil pools, one decade for cropland management changes, and two decades for LULC conversion)

- Permanence of sequestration to address differences in how much carbon remains sequestered over time for each mitigation activity

The product of the first two measures recognizes activities that may result in smaller changes in rates of sequestration, but that are applicable to a vast quantity of lands (for example, rangelands). In addition, the priorities of consulting agencies will be considered in the selection of mitigation activities for the assessment.

Candidate mitigation activities listed in table 3.5 of this report are aligned with those incorporated into the Forest and Agriculture Sector Optimization Model with Greenhouse Gases (FASOM–GHG) (Murray and others, 2005) to provide perspective on the scope of the assessment and to indicate common areas where FASOM–GHG methods, data sources, and results for mitigation activities will be informative for the methodology (table A1). Not all FASOM–GHG mitigation strategies are within the scope of the assessment; for example, the category of fossil-fuel mitigation from crop and livestock production will not be used. Conversely, some mitigation activities not represented in FASOM–GHG are included as candidate mitigation activities in the assessment.

The mitigation activities will be researched before presentation to policy makers and the consulting agencies. The legislation requires the Secretary of the Interior to consult with the Secretary of Energy, the Secretary of Agriculture, the Administrator of the Environmental Protection Agency, the Secretary of Commerce (acting through the Under Secretary for Oceans and Atmosphere), and the heads of other relevant agencies. The candidate mitigation activities priorities will be discussed at a national workshop, but final selection will be subject to data availability, acceptance of assumptions, and model capabilities. Mitigation activities that currently (2010) are operational for the assessment are listed in table A2.

Land-use change is measured as the number of hectares of LULC class change. Within LULC classes, land-management activities are measured as the number of hectares of land-management change. Land management is complex because any one type of land management can be implemented with varying intensity. By way of example, Adams and others (1996, 2005) defined and used regional forest-management-intensity classes, ranging from passive to high-intensity management, for their analyses of carbon-sequestration supply. For the assessment, land management "carbon-sequestration intensity" relates to carbon-sequestration rate. For example, carbon optimal harvests that maximize sequestration in the forest ecosystem and wood products are of greater "carbon-sequestration intensity" than economically optimal harvest rotations (Huang and Kronrad, 2001). Analogies for croplands include crop rotation (versus monocultures) and tillage intensity (Choi and Sohngen, 2009). Carbon intensities of grazing-land management will be framed by recent (2010) rangeland and grassland research (Follett and others, 2001; Bremer and Ham, 2010; Brown and others, 2010).

Also specified at the national level are guidelines to construct alternative mitigation scenarios that are portfolios of mitigation activities, with details on the amounts of change and the timing of implementation. At the regional level, three alternative mitigation scenarios are constructed relative to a reference scenario. The storylines behind each set of reference and alternative scenarios need to be interpreted at the national level to ensure consistency across ecoregions.

A.2. National Interpretation of Storylines

The next step toward creating a set of regional LULC and land-management scenarios is to develop a set of national storylines consistent with the IPCC SRES. This step will be done primarily through a national workshop. Using existing LULC projections associated with the IPCC SRES scenarios and other supporting data as a guide, expert opinion will be solicited to describe plausible reference scenarios of LULC and land management based on the underlying assumptions of the SRES storylines. National storylines can be viewed as thematically enriched sets of SRES storylines with characteristics specific to United States land use and land management. Nakicenovic and others (2000) provided the following narratives and assumptions for each of the SRES scenario families (table A3). For more complete descriptions of SRES storylines, see Nakicenovic and others (2000).

The A1 storyline and scenario family describes a future world of rapid economic growth, minimal or decreasing population growth, and the introduction of new and more efficient technologies. The primary underlying themes are convergence among regions, capacity building, and increased cultural and social interactions, with a substantial reduction in regional differences in per-capita income. The A1 scenario family develops into four groups that describe alternative technological changes in the energy system.

The A2 storyline and scenario family describes a heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge slowly, which results in population growth. Economic development primarily is regionally oriented, and per-capita economic growth and technological changes are more fragmented and slower than in other storylines.

The B1 storyline and scenario family describes a convergent world with the same low population growth as in the A1 storyline, but with rapid changes in economic structures toward a service and information economy, with reductions in material intensity, and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social, and environmental sustainability, including improved equity, but without additional climate initiatives.

A primary deliverable of the national workshop will be expanded LULC narratives and national-scale LULC trajectories. Nested within the national narratives will be assumptions on the regional variability of LULC and management where available (fig. A1.) For example, a national-scale narrative

Table A1. Candidate mitigation activities compared with strategies associated with the Forest and Agriculture Sector Optimization Model with Greenhouse Gases.

[Modified from Murray and others (2005). FASOM–GHG, Forest and Agriculture Sector Optimization Model with Greenhouse Gases; CH_4, methane; N_2O, nitrous oxide; GHG, greenhouse gas]

Strategy/activity	Candidate mitigation activities	Mitigation activities tracked in FASOM-GHG
Afforestation carbon sequestration	Convert lands to forest[1]	Convert agricultural lands to forest.
Forest management carbon sequestration	Lengthen timber harvest-regeneration rotation Increase forest management intensity (increasing forest density, thinning, fire-fuel reduction, insect and disease management) Preserve forests[1]	Lengthen timber harvest-regeneration rotation. Increase forest management intensity. Preserve forests.
Forest management CH_4 and N_2O mitigation	Reduce deforestation[1]	Reduce deforestation.
Agricultural soil carbon sequestration	Reduce cropland tillage Crop mix change to high-residue crops Increase efficiency of crop fertilization Convert grasslands and perennial crops[1] Increase winter cover crops Reduce summer fallow Restore agricultural land Increase irrigation efficiency	Change crop tillage. Change crop mix. Change crop fertilization. Convert grassland.
Fossil-fuel mitigation from crop production		Change crop tillage. Change crop mix. Change crop input. Change irrigated/dry land mix.
Agricultural CH_4 and N_2O mitigation	Reduce cropland tillage Improve crop mix Increase efficiency of crop fertilization Reduce rice acreage[1]	Change crop tillage. Change crop mix. Change crop input. Change rice acreage. Change irrigated/dry land mix. Control enteric fermentation. Change livestock herd size. Change livestock system. Manage manure.
Grassland/rangeland soil carbon sequestration	Improve grazing management practices Restore degraded rangelands Improve use of fertilizer Allow natural succession towards native shrub and forest	Not applicable.[2]
Rangeland GHG mitigation	Reduce severe rangeland fire	Not applicable.
Grassland GHG mitigation	Avoid conversion to energy crops[1]	Not applicable.
Wetland carbon sequestration (negative impact on CH_4)	Preserve, construct, and restore wetlands[1]	Not applicable.
Wetland carbon mitigation	Preserve wetlands[1]	Not applicable.
Urban land carbon sequestration	Increase urban forests	Not applicable.
Barren land carbon sequestration	Reclaim mined lands[1]	Not applicable.
Wood product sequestration	Improve mill waste recovery Extend life of wood products Extend storage in landfills	Change wood product mix.
Wood product GHG mitigation	Improve logging	Not applicable.
Fossil-fuel mitigation	Not applicable	Produce crops for biofuel use.
Technological potential for carbon sequestration	Use biochar Restore degraded rangelands	Use biochar (under investigation).
Aquatic GHG mitigation	Reduce nutrient export from urban and agricultural lands Alter withdrawal from deep reservoirs	Not applicable.

[1]Indicates a land-use change in the assessment (as distinct from a land-management change).

[2]FASOM–GHG 2010 has expanded rangeland and grassland categories and therefore can track LULC changes in these categories, but no mitigation activities are currently implemented.

might include assumptions on forest use while highlighting certain regions as likely places for changes in forestry.

In figure A1, the primary graph begins with the solid black line which denotes measured LULC change based on the USGS Land Cover Trends project (Loveland and others, 2002). In this figure, the trends data represent national estimates for a hypothetical LULC class from 1970 to 2000. The subsequent solid-red line represents LULC composition as modeled using the “forecasting scenarios of land cover change” (FORE–SCE) model based on actual LULC measurements from the 2006 National Land Cover Database (NLCD) change product and LANDFIRE vegetation change tracker (VCT) products as inputs for 2001 through 2010. The set of three dashed-green lines that follows represents hypothetical trajectories of the same LULC class for each of the scenarios in the IPCC SRES for the United States. The inset graph represents the spatial and temporal variability of LULC composition for the A1B SRES scenario across assessment units (U.S. Environmental Protection Agency’s Level II ecoregions, modified from Omernik (1987). The different colors represent discrete geographic regions.

Table A2. Mitigation activities included in 2001 dataset of land-use and land-cover starting points.

[These mitigation activities have been implemented in simulation models proposed for use in this methodology. A discussion can be found in section 3.2 of this report. USGS EROS, U.S. Geological Survey Center for Earth Resources Observation and Science; USDA NASS, U.S. Department of Agriculture National Agricultural Statistics Service; USDA FIA, U.S. Department of Agriculture Forest Service Forest Inventory and Analysis Program; LANDFIRE, Landscape Fire and Resource Management Planning Tools]

Mitigation activity	Data source
Irrigation	USGS EROS National Irrigation Map.
Drainage	USGS EROS National Irrigation Map.
Fertilization	USDA NASS.
Residue management	Residue management county statistics.
Tillage	USDA NASS.
Crop rotation	USDA NASS.
Grazing	USDA NASS.
Manure application	USDA NASS.
Forest cutting	USDA FIA.
Forest thinning	USDA FIA.
Fuel treatments	LANDFIRE.

A.3. Ecoregion Reference Scenario Construction

Regional reference scenarios build from the national storylines discussed above. The foundations of regional scenarios are LULC and land-management histories developed through review of existing historical data sources, including the comprehensive analysis of recent historical LULC change from the USGS Land Cover Trends research project (Loveland and others, 2002). Regional expert consultations will be used to project recent historical LULC into the future based on the current (2010) understanding of the interaction of drivers of LULC change. Regional experts will link SRES and national LULC and management storylines with the biophysical and socioeconomic characteristics of ecoregions to provide a range of LULC and management futures consistent with historical observations.

The scenario construction process also may incorporate exogenous projections of particular LULC types or management. Examples include projections of population from the U.S. Census Bureau or the USFS’s 2010 RPA land-use projections; however, maintaining fidelity with the SRES storylines is required, and the regional expert consultation process will determine the degree to which these exogenous projections are used, if at all. Other coarse-scale LULC modeling efforts, such as those provided by IPCC SRES modeling teams, can be empirically downscaled and combined with existing expertise in LULC science, LULC histories reported in existing studies, and regional expert knowledge to construct regional LULC scenarios for each ecoregion. Constraints on scenario construction primarily are the SRES storylines and existing

Table A3. Qualitative characteristics associated with three scenario families from the Intergovernmental Panel on Climate Change Special Report on Emission Scenarios.

[Modified from Nakicenovic and others (2000). GDP, gross domestic product]

Scenario characteristics	Special Report on Emission Scenarios storyline		
	A1B	A2	B1
Population growth	Low	High	Low.
GDP growth	Very high	Medium	High.
Energy use	Very high	High	Low.
Land-use changes	Low	Medium high	High.
Resource availability	Medium	Low	Low.
Pace and direction of technological change	Rapid	Slow	Medium.
Technological change favoring	Balanced	Regional	Efficiency and dematerialization.

knowledge of regional LULC change. This flexible framework creates opportunities to explore a wide range of regional LULC scenarios, and remain consistent with overall SRES assumptions and characteristics.

A.4. National Interpretation of Storylines for Alternative Mitigation Scenarios

Interpretation of the national storyline is expanded to support construction of the alternative mitigation scenarios. A mitigation scenario is a combination of future potential LULC and land-management changes (activities) associated with vetted climate and socioeconomic conditions to illustrate possible GHG mitigation capacities with various assumptions. There is no precedent for constructing alternative mitigation scenarios for the IPCC SRES. The USFS RPA assessment has not embarked on this endeavor. Alteration of the reference scenario to explore mitigation activities to enhance carbon sequestration and reduce GHG emissions compromises the internal consistency of a reference scenario that is devoid of carbon-sequestration policy. Notably, carbon-sequestration policy that leads to reduced GHG emissions and increased carbon sequestration affects climate, but this effect cannot be captured without modeling policy changes at the global scale. Although the more recent representative concentration pathways (RCP) effort (Moss and others, 2010) avoids this problem by finding alternative scenarios for each radiative forcing target, it requires scenarios to meet carbon sequestration and GHG-emission reduction targets, rather than explore ecosystem capacity. The methodology accepts climate incongruity for alternative scenarios. Conceptually, it is easier to guard the storyline for changes in land management (M), although changes in land management have implications for yields and consumption patterns. Departure from the storyline is exaggerated by LULC changes to enhance carbon sequestration (L and ML) because of competing uses for land to produce food, fiber, and energy for the population. The IPCC SRES storylines are used to motivate a diverse set of alternative mitigation scenarios emphasizing mitigation activities, different change amounts, and different concerns for the temporal aspects of carbon sequestration, including time-effectiveness and permanence of sequestration.

The three storylines are differentiated by assumptions that will be related to emphases on mitigation activities, amounts of change, and importance of timing and permanence of carbon sequestration. Examples are described below:

- For IPCC SRES storyline A1B—
    - The freeing of natural resources could enable afforestation
    - The emphasis on management versus conservation is more likely to promote plantations rather than natural forest
    - The pervasiveness of urban sprawl may restrict reductions in the rates of urban development
    - The technological progressiveness of A1B may justify technological feasibility of biochar and rangeland restoration
- For IPCC SRES storyline A2—
    - The increased or large population growth and focus on sustainable food production may limit conversion of agricultural lands to forest lands, but it may be compatible with agricultural practices that enhance carbon sequestration through conservation tillage, efficient fertilizer usage, crop rotations, and cover crops
    - The concern for water quality for sustainable agriculture may prompt wetland restoration

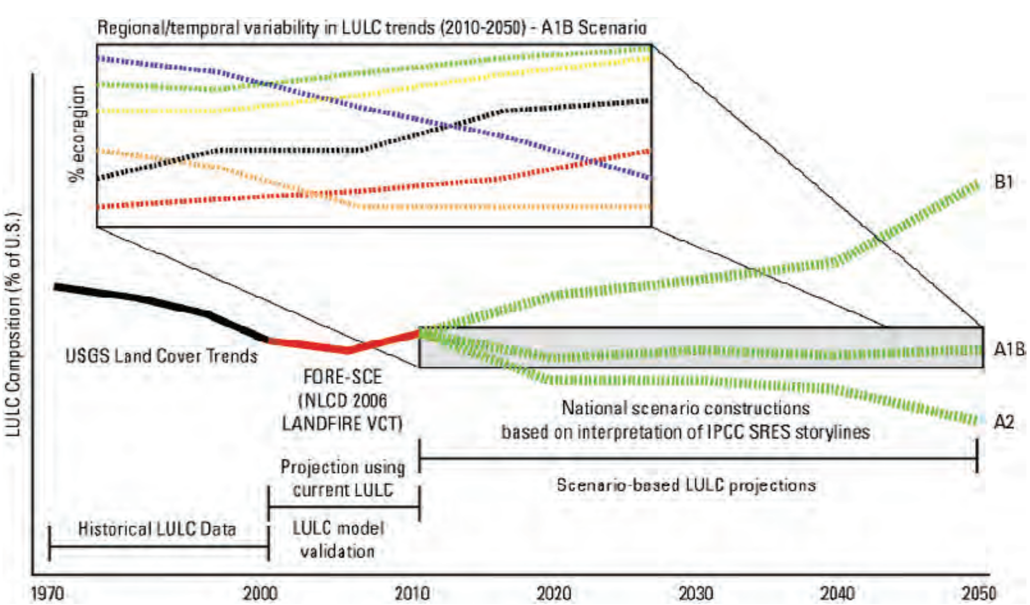

Figure A1. Diagram showing the national and regional scenario scaling concept, showing past, present, and projected land-use and land-cover change. LULC, land use and land cover; FORE-SCE, Forecasting Scenarios for Future Land Cover model; NLCD, National Land Cover Database; LANDFIRE, Landscape Fire and Resource Management Planning Tools; VCT, vegetation change tracker; IPCC, Intergovernmental Panel for Climate Change; SRES, Special Report on Emission Scenarios.

- For IPCC SRES storyline B1—
  - The focus on sustainable development may embrace sustainable food production and wetland protection within A2, but it also may include sustainable forestry practices including the following:
    - Afforestation and avoidance of deforestation
    - Expansion of urban forests
    - Forest management for carbon sequestration
    - Native species
  - Resource efficiency may promote slower rates of development and increased urban density
  - The sustainable development focus may value long- and short-term carbon-sequestration activities

Alternatively, national initiatives, similar to Conservation Reserve Program (CRP), for ecological carbon sequestration will be invited from consulting agencies and applied to varying degrees (for example, high, medium, and low levels of national commitment) across the storylines. Either way, the national consultation process will be relied upon to provide national bounds on increases in mitigation activities. Similarly, bounds on mitigation activities in ecoregions also need to be evaluated.

A.5. Ecoregion Evaluation of Mitigation Activities

For each ecoregion, mitigation activities will be examined for relevance (for example, grazing-land management is more prevalent in some ecoregions than others) and evaluated for their potential to sequester carbon and reduce GHG emissions. Evaluating LULC conversions and land-management changes in the ecoregion will identify activities that maximize carbon sequestration to provide an efficient means to construct alternative mitigation scenarios that “optimize” sequestration in the ecoregion given a limited number of scenario simulation runs and no iteration. Furthermore, a transparent evaluation of mitigation activities complements the complex simulations of LULC change and biogeochemical modeling. Evaluating mitigation activities is accomplished by using results from regional studies of carbon-sequestration-mitigation activities, consulting with regional experts (for example, GRACEnet participants), and developing a spreadsheet tool. Two objectives of GRACEnet are to identify an agricultural system that most likely maximizes soil carbon sequestration and to identify an agricultural system that minimizes net global warming potential (Jawson and others, 2005; U.S. Department of Agriculture, Agricultural Research Service, 2010). As a result of carbon-sequestration research, some regional studies of mitigation activities are readily available. For example, relevant studies about mitigation activities in the Mississippi Alluvial Plain and Mississippi Valley Loess Plains ecoregions include the following.

- Loblolly pine harvest rotations (Huang and Kronrad, 2006; Sohngen and Brown, 2008)
- Fertilization of loblolly pine plantations (Fox and others, 2007)
- Sequestration from softwood (evergreen) forest versus hardwood (deciduous) forest (Sohngen and Brown, 2006)
- Reforestation of poorly stocked pine plantation (Huang and others, 2004)
- Conservation tillage (Franzluebbers, 2005)
- Cotton rotations including pasture (versus monoculture) and with cover crops (Causarano and others, 2006)
- Restoration of bottomland forests (Wainger and King, 2001; Jenkins and others, 2009).

These studies provide details on potential land-management and LULC change for the ecoregion. State climate-change studies provide further indications of the potential to enhance sequestration. For example, the Arkansas Governor’s Commission on Global Warming plan sets a target of 4 percent increase in urban trees by 2025 (Arkansas Governor’s Commission on Global Warming, 2008). Consulting with regional experts will further develop a knowledge base for mitigation-activity potential to enhance sequestration capacity in the ecoregion.

A spreadsheet tool will be used to synthesize available study results and fill in details on carbon sequestration. The tool will present aggregated planning-level estimates of how annual rates of carbon sequestration and cumulative carbon sequestration will change with time as a result of changes in LULC and management from time of implementation. (This is in contrast to the reference and alternative scenarios that stage the implementation of the mitigation activities with time.) The spreadsheet tool will enable exploration of the sensitivity of carbon sequestration to forest management (thinning, harvest rotation, and sequestration in wood products) and agricultural crop rotations of importance to the ecoregion, as needed. A similar spreadsheet tool was developed for the U.S. Environmental Protection Agency (EPA) in the late 1990s and implemented for Omernik’s (1987) ecoregions (Dennis King, University of Maryland, written commun., 2010). The Natural Capital Research Group at the University of Maryland Center for Environmental Science (UMCES) developed a spreadsheet approach during 1996 and 1997 for the EPA Office of Policy Analysis, in preparation for the 1997 Kyoto Conference. When the United States pulled out of the Kyoto negotiations in 1998, the project was suspended; the spreadsheet results for 22 management activities were not published, although they were used in 1999 and 2000 in a project for the EPA Office of Air to show how one might “score” domestic carbon trading that involved land-based carbon sequestration. Although this tool needs updating, further development, and refinement for the assessment, the effort provides a proof of concept.

The mitigation-activity spreadsheet tool will be developed to report results for each of the assessment units with calculations made at the regional and subregional levels. Each spreadsheet will show the expected change (gains, losses, and net) in carbon sequestered resulting from a specific LULC or management activity to another during three periods: a transitional term of 15 years, the medium term of 16 to 40 years, and the longer term of 41 to 100 years, or to an endpoint deemed appropriate for the mitigation activity (as the capacity of some forest ecosystems to sequester carbon is not captured within the 40-year horizon of the assessment). The results will be backed up by detailed tables showing how aboveground, belowground, and on-ground carbon is expected to increase and decrease with time. The spreadsheets will refer to the models that generated them (for example, the Century model from Parton and others (1993)) so that users interested in moving beyond planning-level estimates to consider specific policies in specific jurisdictional boundaries will have access to more detailed and precise numbers.

A column for hectares of suitable or available land for each mitigation activity will be inserted to complete estimates of total carbon potential for the activity and to provide an upper bound on change amount. Designating and bounding suitability is not a well-defined task. The FASOM–GHG conversion (for example, pasture to forest) suitability was derived from Natural Resources Conservation Service (NRCS) land surveys and expert opinion (Adams and others, 1996). The FORE–SCE probability surfaces indicate relative suitability of land for LULC. There are limits on land-management suitability, as well. For example, the benefit of no-till methods in heavy clay soils is questionable (Rochette and others, 2008).

A concept related to suitability is availability, which is the supply of hectares of mitigation activities for a price (Brown and Kadyszewski, 2005); therefore, suitability also is indicated by the hectares of mitigation activities supplied at a high carbon price. In short, various data sources and model results provide indications of hectares of suitability and availability; for the prototype study region, the availability of bottomland forest was taken from the marginal land analysis of Wainger and King (2001). The percentage change in bottomland forest was noted to fall within the percentage change of national afforestation estimated by FASOM–GHG for the $50-per-tonne (megagram) price (Murray and others, 2005) and the USDA (Lewandrowski, 2004). Similarly, the national results from the latter two studies were used to indicate conservation tillage change bounds, but regional results from those studies could be accessed for the assessment. The increase in urban forests was adopted from the State climate-change plans. Regional consultation also will be used to indicate bounds on the suitability and availability of hectares for mitigation activities in the ecoregion.

The assessment unit spreadsheets for mitigation activities will be populated as follows:

1. Available studies and regional subject expertise will be used to specify the mitigation activities for each LULC class in the assessment unit.
2. The Carbon Online Estimator (COLE; U.S. Department of Agriculture, U.S. Forest Service, 2010a), the Voluntary Reporting of Greenhouse Gases-Carbon Management Evaluation Tool (COMET–VR; U.S. Department of Agriculture, Natural Resources Conservation Service, 2010), and the Century carbon model (which has a user-friendly interface) will be used to estimate annual rates of carbon sequestration for each LULC and management activity within each EPA Level II ecoregion from year 1 (for example, year of transition to the management activity intensity) to year 40 and beyond as appropriate.
3. The results of step 2 will be compared with results of earlier nationwide research (for example, Sperow and others, 2003).
4. The number of hectares in each LULC class and land-management carbon-intensity class for the starting conditions for each EPA Level II ecoregion (section 3.2 of this report) will be obtained.
5. The hectares of LULC class suitability will be estimated using FORE–SCE probability surfaces, estimates from other studies (for example, FASOM–GHG suitability estimates based on data from the National Resources Inventory (NRI) of the NRCS)), and regional consultation, as will land-management suitability limits.
6. A spreadsheet tool for each EPA Level II ecoregion will be prepared (see table A4 for a sample report).
7. Instructions and caveats about using the spreadsheet data, providing explanations about how spreadsheet numbers were generated, and links back to underlying simulations and models will be documented.

For users outside of the assessment, additional steps can be implemented to refine a spreadsheet tool to organize information for various spatial scales, such as counties and States, and to package spreadsheet tools in various ways to support the needs of users.

A.6. Alternative Mitigation Scenario Construction for Ecoregions

For an ecoregion, three alternative mitigation scenarios will be constructed to enhance carbon sequestration and reduce GHG emissions through land management (M), LULC change (L), and both (ML) for each storyline. Each set of storyline alternative mitigation scenarios will be built from national guidelines regarding mitigation activity emphases (for example, managed versus natural), commitments to change (for example, high, medium, low), and aggressiveness of carbon sequestration (for example, urgent, constant, delayed). The evaluation of the mitigation activities, described above, provides the means by which to specify mitigation activities that maximize carbon sequestration, to bound mitigation activity change within the ecoregion and storyline, and to indicate carbon sequestration with time.

Table A4. Sample spreadsheet format adapted from earlier spreadsheets for the U.S. Environmental Protection Agency.

[GHG, greenhouse gas; LULC, land use and land cover; Mg/ha/yr, megagram (metric ton) per hectare per year]

Ecoregion 1	From agriculture, croplands, harvested, conventional tillage, no cover crops	Hectares of mitigation activity		Carbon sequestration rate from "no change"				Other GHG emissions
		Starting	Suitable	Years 1–15 (Mg/ha/yr)	Years 16–40 (Mg/ha/yr)	Years 41–100 (Mg/ha/yr)	Years 1–40 (Mg/ha/yr)	
LULC class	**To**							
Agriculture, croplands, harvested	Conventional tillage, no cover crops							
	Conventional tillage, cover crops							
	Conservation tillage, no cover crops							
	Conservation tillage, cover crops							
Agriculture, croplands, idle	Agriculture, permanent grass							
	Agriculture, wetlands							
Forestry, deciduous	Deciduous, 0–15 years							
Forestry, evergreen	Evergreen, 0–15 years							
Pasture/rangeland	Pasture/rangeland, herbaceous							

In the absence of national and regional consultation, a preliminary example of an alternative mitigation scenario for the sample region is provided for illustrative purposes in table A5. The features of an alternative enhanced scenario (for example, ML scenario for the A1B storyline (denoted as A1B_ML)) are:

- Net change from 2010 to 2050 of the alternative scenario reported against the net change of the reference case
- LULC change implemented at an annualized rate of the net change (constant implementation)
- Reasons for and amounts of LULC changes, and constraints on conversions
- Reasons for and amounts of land-management changes within LULC classes

Supporting references for each of the two types of mitigation activities in these ecoregions were noted in section A.2. Except for bottomland forest restoration in the Mississippi Alluvial Plain (where a study proposed acres of conversion), land-use percentages and management change are fabricated in the absence of a functioning regional consultation process.

There are many other factors that affect realized sequestration capacity including cost, technological feasibility, effects on ecosystem functions and services, energy usage, and policy implementation. The primary purpose of the scenario construction is to assess the ecological sequestration capacity of ecosystems. Demonstrating relations between carbon sequestration and other factors are provided in chapter 3 of this report and appendix F.

A.7. National and Regional Consultation Processes

A.7.1. Framework for Engaging Expert Opinion to Calibrate Models

An important conceptual component of the modeling process is consultation. The goal of this consultation process is to ensure that the constituents of the reference and alternative mitigation scenarios being modeled in the assessment are relevant at the scale of the assessment unit. Further, it is desirable, and indeed necessary, that the processes and assumptions used to construct scenarios (and constituents) are consistent across ecoregions so that comparisons are valid. The assessment will engage regional experts to ensure regional relevance operating within a national framework to ensure consistency.

The assessment requires the integration of somewhat disparate models and project components, and consequent fields of expertise, such as LULC change, land-management change, biogeochemical modeling, policy, and economics. As such, the approach to calibrating modeling components will be split into two branches (fig. A2). One branch of the calibration process will focus on reference scenario development; the other will focus on mitigation scenario development. The two calibration branches are not independent, but can proceed in parallel with careful scheduling. Each of the two branches will be led by a subgroup in the assessment; the subgroup members will maintain contact with the other subgroup through the project leadership group. To improve the efficiency and outcomes of the calibration process, external organizations with significant experience in working with experts may be retained and used to help develop protocols, materials, and tools where needed.

An important aspect to all scales of scenario construction is the use of historical LULC, rates of LULC change, land-management dynamics, and other related data, both spatial and nonspatial. Examples of such data are found in table A6. These data will first be used during national reference scenario construction and consultation to document the historical trajectories of variables affecting U.S. LULC change and management, inform experts about spatial variability of U.S. LULC change, and provide a historical baseline from which to project changes in LULC and management under alternative scenarios.

A.7.2. National Reference Scenario Development (Box A in Figure A2)

The foundation of the assessment process is a suite of SRES-based reference scenarios. The three SRES scenarios will be interpreted, and a narrative description will be developed. These three storylines comprise the national reference modeling scenarios. These national, initial “strawman” reference scenarios will be reviewed and refined by a wide array of relevant experts at a national workshop. Comments and suggestions from a geographically diverse set of workshop participants will be reviewed and incorporated where needed. The outcome of this process will be a set of national-level, reference storylines and scenarios. At this scale, focus is on developing qualitative storylines rather than quantitative scenarios. The storylines will be the primary product used to develop regional land-use scenarios.

A.7.3. National Mitigation Scenario Development (Box B in Figure A2)

One of the key questions to be addressed for the assessment is which of the mitigation activities have the greatest potential to increase carbon sequestration and GHG fluxes. Because land-change modeling and biogeochemical assessment models are a central part of the methodology, the list of candidate mitigation activities must be compared against the capabilities of the models and data availability to ensure that they are compatible. A national consultation with a diverse set of experts will be used to obtain additional external review of the list of mitigation activities, prioritize mitigation activities for the assessment, set national guidelines for plausible maximum mitigation activity change, and provide guidelines on the assignment of mitigation activities to the storylines. Supplemental small meetings with specific relevant experts also may be held to ensure that a variety of stakeholder interest groups are represented. The outcome of this process will be a national set of guidelines for implementing mitigation scenarios to increase carbon sequestration and reduce GHG emissions at the regional level.

A.7.4. Regional Reference Scenario Development (Box C in Figure A2)

To improve the relevance of assessment results at regional levels, the national reference scenarios will be downscaled to EPA Level II ecoregions (assessment units; modified from Omernik, 1987). To accomplish this important goal, a series of regional consultations will be conducted. Relevant assessment staff will identify and engage key experts in each ecoregion. Because many of the ecoregions are quite large, the team will explore using model input ranges based upon regional expert suggestions (for example, various data scales from the U.S. Census Bureau) with qualitative (for example, types of specific LULC transitions) and quantitative (for example, overall national rates of LULC change) constraints developed during the national scenario development stage to guide regional scenario construction. The results of this development process are a critical input to the next step in the process—developing regional-level mitigation scenarios.

A.7.5. Regional Mitigation Scenario Development (Box D in Figure A2)

Results from the national mitigation scenario workshop and regional reference scenario consultations are combined in this final step aimed at regionalizing mitigation scenarios. Regional experts will be engaged to work from a set of activities from the national list in the context of the reference scenarios developed for that region. Regional engagement may be organized through regional entities such as the U.S. Fish and Wildlife Service’s Landscape Conservation Cooperatives (LCC) and the U.S. Department of Interior’s initiative for Climate Science Centers. Regional experts will suggest changes to the selected mitigation activities to improve local and regional relevance, will review the synthesis of relevant research and spreadsheet results, and will review three

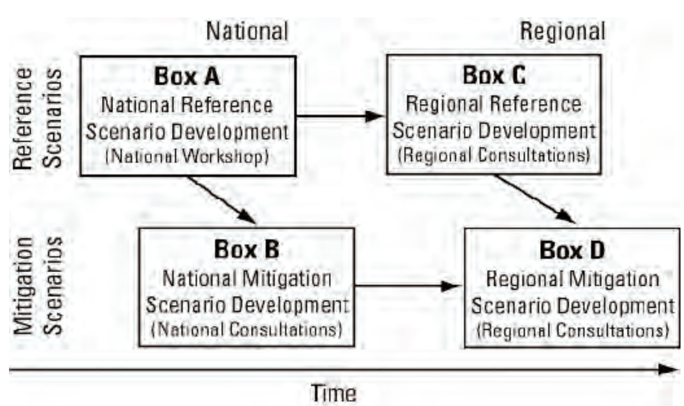

Figure A2. Diagram showing the national and regional consultation process to obtain expert knowledge to calibrate scenarios for the assessment.

Table A5a. Reference A1B_R and alternative scenario A1B_ML for Mississippi Alluvial Plain.

[km^2, square kilometers; lbs/acre, pounds per acre (multiply by *x* to obtain kilograms/hectare); LULC, land use and land cover; N, nitrogen; P, phosphorus]

LULC class	2010 LULC (km^2)	A1B_R net change 2010–2050 (percent LULC class)	A1B_L net change 2010–2050 (percent LULC class)	2050: A1B_L-R (km^2)	LULC change comments/directions	Land management change comments/directions
Water	13,084	10.8	10.8	0	No reduction in coastal wetlands	
Developed	9,855	12.9	12.9	0	No reduction in development (urban sprawl), no conversion of wetland to developed	Increase urban forestry: five trees per capita over next 15 years.
Barren	251	-1.6	-1.6	0	Mostly sand, not suitable for sequestration activities	
Mining	6	-3.9	-3.9	0	Mine lands ignored because of small size of area	
Mechanically disturbed	140	0.5	-48.8	-69	Reduced by doubling harvest rotation (with thinning)	
Fire disturbed	4	0.0	0.0	0	Forest-fire management maintains disturbance despite afforestation	
Deciduous forest	2,826	-16.5	-16.5	0	Reduce deforestation	
Evergreen forest	2,272	0.2	32.2	728	Favor plantations	Increase stock on understocked land. Fertilize at planting: 200 lbs/acre N and 25 lbs/acre P.
Mixed forest	1,505	-17.6	-17.6	0	Reduce deforestation	
Shrub/scrub	0	0.0	0.0	0		
Grassland	0	0.0	0.0	0		
Hay/pasture	4,352	12.1	6.1	-264	Reduce the R scenario increase in pasture for conversions to bottomland forest restoration Increase pasture/crop rotations by 10 percent	
Row crops	62,620	-2.4	-16.4	-8767	Conversions of marginal croplands to bottomland forest restoration Increase pasture/crop rotations by 10 percent	Implement conservation tillage up to 50 percent of cropland. Implement wheat cover crop on 50 percent of cotton acreage. Increase cotton-soybean crop rotations (to reduce monocultures). Reduce rice acreage by 50 percent.
Woody wetlands	27,048	-1.9	29.1	8,372	Restore 2 million acres of bottomland forest	
Herbaceous wetlands	8,191	-6.1	-6.1	0	Avoid conversion of wetland to developed	
Total	132,468	0.0	0.0	0		

Table A5b. Alternative scenario A1B_ML for Mississippi Valley Loess Plains.

[km^2, square kilometers; lbs/acre, pounds per acre (multiply by *x* to obtain kilograms/hectare); LULC, land use and land cover; N, nitrogen; P, phosphorus]

LULC Class	2010 LULC (km^2)	A1B_R net change 2010–2050 (percent LULC class)	A1B_L net change 2010–2050 (percent LULC class)	2050: A1B_ L-R (km^2)	LULC change comments/directions	Land management change comments/ directions
Water	562	26.3	26.3	0	No reduction in coastal wetlands	
Developed	4,998	38.8	38.8	0	No reduction in development (urban sprawl), no conversion of wetland to developed	Increase urban forestry: 5 trees per capita over next 15 years.
Barren	72	0.0	0.0	0	Mostly sand, not suitable for sequestration activities	
Mining	16	-11.1	-11.1	0	Mine lands ignored because of small size of area	
Mechanically disturbed	424	0.5	-49.6	-213	Reduced from doubling harvest rotations (with thinning)	
Fire disturbed	3	0.0	0.0	0	Forest-fire management maintains disturbance despite afforestation	
Deciduous forest	11,379	2.0	2.0	0	Reduce deforestation	
Evergreen forest	4,831	20.6	33.9	641	Favor plantations	Increase stock on understocked land. Fertilize at planting: 200 lbs/acre N and 25 lbs/acre P.
Mixed forest	4,681	3.4	3.4	0	Reduce deforestation	
Shrub/scrub	0	0.0	0.0	0		
Grassland	0	0.0	0.0	0		
Hay/pasture	5,008	-35.5	-35.5	0	Increase pasture/crop rotations by 10 percent	
Row crops	9,536	-15.2	-22.1	-657	Increase pasture/crop rotations by 10 percent	Implement conservation tillage up to 50 percent of cropland. Implement wheat cover crop on 50 percent of cotton acreage. Increase cotton-soybean-crop rotations (to reduce monocultures). Reduce rice acreage by 50 percent.
Woody wetlands	4,065	-5.7	0.0	233	Prevent further loss of woody wetlands, no study found to support restoration of woody wetlands	
Herbaceous wetlands	328	-1.4	-1.4	0	Avoid conversion of wetland to developed	
Total	45,903	0.0	0.0			

regional mitigation scenarios for each storyline. It is important to note that process consistency will be maintained throughout these steps by requiring that each successive scenario construction build upon previous stakeholder's or expert's calibration steps.

A.7.6. Schedule Considerations

The two branches of the calibration process interrelate, and careful scheduling of the workshops and consultations will be required to meet overall deadlines. It is important to remember that this calibration process is an early component of the overall production scheme, and delays in the calibration process will cascade down through the schedule and ultimately create delays in the final products. Adequate time for planning workshops and consultations, as well as compiling and interpreting the results, must be explicitly included in the calibration schedule.

The general process is as follows: national reference scenario development (box A in figure A2); national mitigation scenario development (box B in figure A2); regional reference scenario development (box C in figure A2); and regional mitigation scenario development (box D in figure A2); however, these steps are not necessarily sequential. Regional scenario calibrations must precede the corresponding regional mitigation strategy calibration, but the regional scenario calibrations can take place significantly earlier and do not need to proceed on a pace that matches the regional mitigation strategy calibrations.

A.7.7. Approximate Schedule

The approximate schedule is summarized below.

- The national reference scenario workshop likely will occur in the fall of 2010.
- National mitigation scenario workshop and consultations will follow as soon as the final results are available.
- Regional reference scenario consultations require products from the mitigation scenario workshop, therefore they cannot commence until the products are complete and the final results are available.
- Regional mitigation scenario consultations must follow the associated scenario consultation, and they should be completed for each ecoregion well before the products are needed by the modelers.

Table A6. Data sources and characteristics used to inform and develop reference and alternative scenarios.

[USDA, U.S. Department of Agriculture; USGS, U.S. Geological Survey; LULC, land use and land cover; EPA, U.S. Environmental Protection Agency; NRCS, Natural Resources Conservation Service]

Data source	Description	Spatial resolution	Temporal resolution
U.S. Population Census	Decadal population estimates, U.S. population projections	Subcounty (block, block group), county, State	10 years, with annual population projections.
USDA Census of Agriculture	Estimates of crop production	County, State	Every 5 years.
USDA Cropland Data Layer	State maps of crop type	30–60 m, States	Annual; 2000 to present (not national coverage).
USGS Land Cover Trends	Sample-based estimates of LULC change for conterminous United States; reports documenting LULC dynamics	EPA ecoregions (Levels I, II, and III) and States	Every 6 to 8 years between 1973 and 2000.
National Land Cover Dataset and Database (NLCD)	Land-cover map of the conterminous United States	30 m	1992, 2000, 2006.
Forest Inventory and Analysis (FIA) Program of the USDA U.S. Forest Service	Sample-based point locations; characterizations of U.S. forest dynamics	Point-based observations on U.S. forest lands	Annual.
Protected Areas Database of the United States (PAD-US)	Polygons of protected areas of the United States	Feature-based; individual protected areas	Current; each feature has attributed data for establishment of area.
National Resources Inventory (NRI) of the USDA NRCS	Sample-based estimates of land use and other changes (non-Federal lands)	Point-based estimates for States (some local and regional data/estimates also available)	1977, 1982, 1987, 1992, 1997.
National Wetlands Inventory (NWI)	Characterization of wetlands	Feature-based; local to national	Based on source data from 1980s and 1990s.

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