Estimates of Carbon Mitigation Potential from Agricultural and Forestry Activities

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Summary

In the United States, the agriculture and forestry sectors account for 6%-8% of current estimated total U.S. greenhouse gas (GHG) emissions annually. Combined, these sectors are estimated to emit more than 500 million metric tons CO_2 equivalent (MMT CO_2-Eq.) each year, most of which is emitted from the agriculture sector.

Current estimates of the combined amount of carbon sequestered by the agriculture and forestry sectors is reported at more than 1,100 MMT CO_2-Eq. per year, most of which is attributable to carbon stocks and uptake by trees in the forestry sector.

Numerous studies estimate the additional GHG mitigation potential of farm and forestry activities. Among these, two commonly cited studies are those conducted by the U.S. Department of Agriculture (USDA) and the U.S. Environmental Protection Agency (EPA).

Compared to current estimated mitigation potential levels, USDA and EPA projections provide a mostly positive picture of the potential for farm and forestry activities to mitigate GHG emissions. USDA and EPA project added mitigation potential of 590 to 990 MMT CO_2-Eq. annually, thus increasing to roughly double current levels, assuming a high-end value or market price for carbon. At lower carbon prices, estimated additional mitigation potential is lower, but could still add about 40 to 160 MMT CO_2-Eq. annually above current sequestration levels.

These estimates are useful indicators of the potential for carbon storage in the agriculture and forestry sectors, which some in Congress see as potentially available for carbon offset allowances as part of a cap-and-trade program. A cap-and-trade system—as part of a GHG emissions reduction and trading program—is one possible approach being considered by Congress to address GHG emissions in the ongoing climate change debate.

For policy decision-making, however, the results of studies such as those conducted by EPA and USDA to assess the carbon mitigation potential of farms and forests should be viewed with caution. These studies were published in 2004 and 2005, respectively, and use complicated simulation models largely based on data and market assumptions present in the late 1990s to early 2000s. Consequently, the available input data and modeling assumptions are limited in the extent to which they are able to accurately reflect both actual current conditions and longer-term future conditions. Given that these studies were developed prior to a variety of recent policy, market, and economic changes, some researchers now acknowledge that the published results of these studies are almost certainly outdated. Other related concerns include criticisms by prominent researchers of these modeling approaches and estimates. In addition, in the absence of defined policies outlining how an emission trading system would be designed and implemented, these models are limited in the extent to which they can depict future conditions under a regulatory system for sequestering carbon on farms and forests.

In 2009 EPA updated its simulation models and underlying data and modeling assumptions. These changes to EPA's simulation models have implications for the agency's analysis of the overall estimated mitigation potential from agriculture and forestry activities, particularly for certain sequestration categories. Of particular concern to many in the U.S. agriculture sector, EPA's current estimates of the mitigation potential from agriculture soil carbon activities—such as conservation or no-till practices that preserve soil carbon—are sharply lower than previous EPA estimates.

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Introduction

Numerous theoretical and empirical studies estimate the greenhouse gas (GHG) mitigation potential of farm and forestry activities, and suggest that the potential for carbon uptake in agricultural soils and forest lands is much greater than current rates. Among these studies, two commonly cited reports by the U.S. Department of Agriculture (USDA) and the U.S. Environmental Protection Agency (EPA) take a comprehensive approach to assessing the mitigation potential in the agriculture and forestry sectors:

- USDA, *Economics of Sequestering Carbon in the U.S. Agricultural Sector*, April 2004, http://www.ers.usda.gov/publications/tb1909/; and
- EPA, *Greenhouse Gas Mitigation Potential in U.S. Forestry and Agriculture*, November 2005, http://www.epa.gov/sequestration/pdf/greenhousegas2005.pdf.

Each of these studies provide estimates that are useful in approximating the potential for agricultural and forestry activities to mitigate GHGs and store carbon, beyond current estimated sequestration rates. Some in Congress are considering including certain agricultural and forestry activities as carbon offset allowances under a cap-and-trade program,[1] making these activities and estimates of their mitigation potential relevant to the ongoing climate change debate.[2]

Following a discussion of the estimated current emissions and carbon sequestration by the agricultural and forestry sectors, this report presents a brief overview of the available estimates from USDA and EPA carbon mitigation studies, and then discusses some of the limitations of the available data and modeling results. This report is organized into four parts. The first provides a brief overview of the role of the agriculture and forestry sectors within the broader climate change debate, describing available estimates of current GHG emissions and carbon sequestration in the farm and forestry sectors. The second describes available data and information on the potential for carbon storage (tonnage) by type of farming and forestry activity, and presents available estimates of the aggregate carbon sequestration potential in these sectors. The third part discusses some of the limitations of available estimates of GHG mitigation potential in the agriculture and forestry sectors. A more detailed discussion of these concerns is provided in the **Appendix**.

The final part of this report provides a comparison of EPA's previous and its updated estimates of the carbon mitigation potential from farming and forestry activities, following the agency's changes in March 2009 to its simulation models and underlying data and modeling assumptions. These changes to EPA's models have implications for the agency's analysis of the overall estimated mitigation potential from agriculture and forestry activities, particularly for certain sequestration categories. These differences are reflected in modeling results presented in information published by EPA, as well as in the separate EPA analyses of the House-passed climate bill, H.R. 2454.

[1] A cap-and-trade program provides a market-based policy tool for reducing emissions by setting a cap, or maximum emissions limit, for certain industries. Sources covered by the cap can choose to reduce their own emissions, or can choose to buy emission credits that are generated from reductions made by other sources.

[2] For information on the current policy debate and legislative proposals, see CRS Report R40896, *Climate Change: Comparison of the Cap-and-Trade Provisions in H.R. 2454 and S. 1733*; and CRS Report R40994, *Agriculture and Forestry Provisions in Climate Legislation in the 111th Congress*.

Estimated Current Emissions and Sequestration

Farm and forestry activities are a both a source and a sink of greenhouse gases, generating emissions that enter the atmosphere and removing carbon dioxide (CO_2) from the atmosphere through photosynthesis and storing it in vegetation and soils (a process known as sequestration).

The U.S. agriculture and forestry sectors are estimated to annually account for 6%-8% of the nation's total greenhouse gas (GHG) emissions. Combined, these sectors are estimated to emit about 500 million metric tons CO_2 equivalent (MMT CO_2-Eq.) each year, most of which is emitted from the agriculture sector.[3] Current estimates of the combined amount of carbon *sequestered* by the agriculture and forestry sectors is reported at more than 1,000 MMT CO_2-Eq. per year, most of which is attributable to carbon stocks and uptake by trees in the forestry sector (**Table 1**).

Combined, carbon sequestration on farm and forested lands is currently estimated to mitigate about 15% of total annual GHG emissions in the United States. Growth in forest stocks account for the majority of this estimated sequestration, with agricultural soils accounting for a small share of this total.

Table 1. Estimated Current GHG Emissions and Carbon Sequestration: U.S. Agricultural and Forestry Activities, Average 2003-2007

(million metric tons CO_2 equivalent (MMTCO_2-Eq.))

Source	Emissions[a]	Sequestration[b]	Net
Agricultural and Forestry Activities	**530**	**(1,053)**	**(523)**
Agriculture	487	(45)	442
Land Use Change, Forestry[c]	43	(1,008)	(965)
U.S. Total, All Sources	7,150	(1,063)	6,087
% U.S. Total, Agriculture and Forestry Share	7%	4%	—
% U.S. Total, Forestry Share	<0.5%	95%	—

Source: Compiled by CRS from EPA *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2007*, April 2009 (Tables 2-14, 2-12, 7-3, 7-1, and 6-1), http://epa.gov/climatechange/emissions/usinventoryreport.html. Data shown are five-year averages (2003-2007). Corrected numbers based on discussions with EPA staff.

Notes:

a. Includes CO_2, CH_4, and N_2O. Based on reported emissions attributable to the "agriculture" economic sector, but includes land use and forestry values (EPA Inventory, Table 2-14).

b. Measured agricultural sequestration categories include land converted to grassland, grassland remaining grassland, land converted to cropland, and cropland remaining cropland. Forestry includes change in forest stocks and carbon uptake from urban trees. Total also includes landfilled yard trimmings and food scraps.

c. Reported as "Emissions from land-use, land-use changes, and forestry" (EPA *Inventory*, Table 7-3).

[3] GHG emissions from agriculture are associated with livestock operations (as part of the natural digestive process of animals and manure management) and crop production (soil management, commercial fertilizer and manure application, and from the production of nitrogen-fixing crops). The two key types of GHG emissions are methane (CH_4) and nitrous oxide (N_2O). Estimated emissions are expressed on a CO_2-equivalent basis. See CRS Report RL33898, *Climate Change: The Role of the U.S. Agriculture Sector*.

The U.S. forestry sector more than offsets the less than 1% of annual GHG emissions associated with the sector.[4] The U.S. agricultural sector, however, remains a net source of GHG emissions and sequesters only about 4% of the carbon-equivalent GHG emissions generated by the sector each year. Compared to total national GHG emissions, the U.S. agriculture sector offsets well under 1% of all emissions annually.

For more information, see CRS Report RL33898, *Climate Change: The Role of the U.S. Agriculture Sector.*

Estimated Additional Potential Mitigation

Current Estimates of Potential Mitigation by Practice

The types of individual farm and forestry practices that sequester carbon, and thus help mitigate GHG emissions, include a range of commonly used land management, agricultural conservation, and other farmland practices. Examples are shown in the text box.

Agricultural and Forestry Practices That Reduce Emissions and/or Sequester Carbon

Land retirement, conversion, and restoration. Includes conversion/restoration to grasslands, wetlands, or rangelands; and selected structural barriers, such as vegetative and riparian buffers, setbacks, windbreaks.

Cropland tillage practices. Includes reduced/medium-till, no-till, ridge/strip-till versus conventional tillage, soil management/conservation, soil supplements/amendments, soil erosion controls, precision agriculture practices, and recognized best management practices.

Cropping techniques. Includes crop rotations, cover cropping, precision agriculture practices, efficient fertilizer/nutrient (including manure), and chemical application.

Manure and feed management. Includes improved manure storage (e.g., anaerobic digestion) and methane recovery; improved feed efficiency; and dietary supplements.

Grazing management. Includes rotational grazing and improved forage practices.

Bioenergy/biofuels substitution. Includes on-farm use; replacing fossil fuels or deriving bioenergy from land-based feedstocks (renewable energy); and on-farm energy efficiency/conservation.

Afforestation/Reforestation. Includes establishing forested areas by planting trees or their seeds, or creating forested areas through conversion of pastureland and cropland.

Forest management. Includes practices to increase growth on some stems while releasing some carbon (total biomass growth change could be positive or negative); harvest for long-term wood products; reduced impact logging; certified sustainable forestry; thinning/release (mechanical, chemical, prescribed burning); fertilization; and pruning.

Avoided deforestation/forest degradation. Includes emissions when (mostly tropical) forests are burned, degraded, or cleared, and large amounts of carbon are released into the atmosphere.

[4] GHG emissions from forestry are associated with usually from timber cutting, wildfires, and tree decomposition. See CRS Report RL31432, *Carbon Sequestration in Forests.*

This list reflects the range of agricultural and forestry practices that could potentially either reduce or abate GHG emissions and/or sequester carbon. However, the verifiability of agricultural and forestry sequestration within a carbon trading program can be problematic and implies the need for a high standard for what can be counted. Many of these mitigation practices may not be practicable for an emission trading program because they might not be able to meet convincing standards for quantifying, monitoring, and verifying the emission reduction or carbon storage (and, therefore, may have questionable GHG reduction potential in practice).[5]

The inclusion of these or any mitigation practice as part of a federal emissions trading regime will depend on the feasibility of developing protocols to ensure that these types of practices are able to be quantified, monitored, and verified. In fact, a relatively narrow list of farm and forestry practices are being considered as offsets under some of the active or emerging regional climate change initiatives, such as the Regional Greenhouse Gas Initiative (RGGI), the Western Climate Initiative, and California's climate change statute. These programs allow or are considering allowing certain types of agricultural and forestry projects as part of their offset/allowance programs. However, the list of eligible agricultural and forestry activities tends to focus on either high-end, tested technologies (e.g., anaerobic digesters) and/or projects that are fairly easy to measure, verify, and monitor (afforestation and reforestation, manure management, etc.). Many offset/allowance projects under these initiatives tend to be outside the agricultural and forestry sectors, such as landfill gas and wastewater management, reduced CO_2 and sulfur hexafluoride (SF_6) emissions from energy production, and various energy efficiency measures.[6]

Table 2 provides the estimated sequestration rates for selected types of practices, based on the current literature as summarized by USDA and EPA. The estimates show the potential for carbon storage (tonnage) by type of farming and forestry activity.[7] As shown, estimated sequestration rates vary widely, illustrating differences in the literature and uncertainty because of varying site-specific conditions across production regions, differences in the management and implementation of the various practices, and also differences in how these rates are measured across studies, among other factors.

Avoided deforestation is reported to have the greatest estimated potential to sequester carbon, estimated to range from 84 to 172 metric tons of CO_2-equivalent sequestered per acre annually, as reported by EPA. Other land use practices, such as afforestation, conversion and restoration activities, and pasture and rangeland management are reported to have the potential to sequester between about 1 to nearly 10 metric tons of CO_2-equivalent per acre annually. Various changes in cropland and animal production practices are reported to sequester less than, but up to, about 1 metric ton of CO_2-equivalent per acre annually.

[5] See CRS Report RS22964, *Measuring and Monitoring Carbon in the Agricultural and Forestry Sectors*.

[6] Stockholm Environment Institute, *A Review of Offset Programs: Trading Systems, Funds, Protocols, Standards and Retailers*, October 2008, http://www.sei-us.org/climate-and-energy/SEIOffsetReview08.pdf]; RGGI, "Overview of RGGI CO_2 Budget Trading Program," Oct. 2007, http://www.rggi.org/docs/program_summary_10_07.pdf; Western Climate Initiative, *Design Recommendations for the WCI Regional Cap-and-Trade Program*, September 2008, http://www.westernclimateinitiative.org/; and California Environmental Protection Agency, *Expanded List of Early Action Measures to Reduce Greenhouse Gas Emissions in California Recommended for Board Consideration*, Oct. 2007, http://www.arb.ca.gov/cc/ccea/meetings/ea_final_report.pdf.

[7] EPA and USDA used different units to measure the rate of sequestered carbon: USDA's rates are reported in terms of metric tons of carbon sequestered per acre per year (MT C/acre/year), whereas EPA's rates are in metric tons of CO_2 per acre per year (MT CO_2 /acre/year). To convert from EPA-reported CO_2 units to carbon equivalent units, multiply CO_2 by 0.2727. To convert from carbon to CO_2 equivalent units, multiply by 3.667. Where applicable, CRS converted rates of carbon to CO_2 equivalent units. Most legislative proposals use CO_2 as the unit of measurement.

Table 2. Estimated Sequestration Potential by Practice (Annual per Acre): Selected Land Use and Production Practice Changes

(MT CO2-Eq. sequestered per acre per year)

Activity	EPA (2005)	USDA (2004)
Forestry		
Afforestation (previously cropland/pasture)	2.2 - 9.5	2.7 - 7.7
Reforestation	1.1 - 7.7	—
Avoided deforestation	83.7 - 172.1[a]	—
Changes in forest management	2.1 - 3.1	—
Cropland/Land Use changes		
Afforestation of croplands	—	2.9 - 6.3
Afforestation of pastureland	—	2.7 - 7.7
Cropland conversion to grasslands	0.9 - 1.9	0.9 - 1.9
Restoration of wetlands	0.4	—
Riparian or conservation buffers (non-forest)	0.4 - 1.0	0.5 - 0.9
Production/Grazing Practice Changes		
Reduced/conservation tillage	0.6 - 1.1	0.3 - 0.7
Improved rotations, cover crops, elimination of summer fallow	—	0.2 - 0.4
Improved fertilizer management	—	0.1 - 0.2
Improved irrigation management	—	0.2
Use of manure/byproducts on pasture	—	0.7 - 1.8
Rangeland management	—	0.2 - 0.6
Pastureland management	—	0.4 - 1.8
Grazing management	0.1 - 1.9	1.1 - 4.8
Other		
Biofuels substitutes for fossil fuels	4.8 - 5.5	—

Source: EPA, Greenhouse Gas Mitigation Potential in U.S. Forestry and Agriculture, Nov. 2005, Table 2-1, http://www.epa.gov/sequestration/greenhouse_gas.html; and USDA, Economics of Sequestering Carbon in the U.S. Agricultural Sector, Apr. 2004, Table 2.2, http://www.ers.usda.gov/publications/tb1909/. Applicable citations and footnotes are available in the original studies. USDA values are converted from reported metric tons of carbon sequestered per acre per year (multiplied by 3.667; see footnote 7), rounded to nearest tenth. "—" indicates that estimates were not reported by the studies.

Notes:

a. Values represent the assumed CO_2 loss avoided by not cutting the forest. The amount remains the same year after year, as long as the forest is not cut, and thus is comparable to annual estimates from other options. Low and high national annual average per acre estimates based on acres deforested from National Resource Inventory (NRI) data and carbon stock decline from the FORCARB model, from 1990 to 1997. Reported in U.S. government submission documents: "United States Submission on Land-Use, Land-Use Change, and Forestry," August 2000, http://www.state.gov/www/global/global_issues/climate/000801_unfccc1_subm.pdf.

For other information on the types of farm and forestry activities that may reduce and/or sequester carbon, see CRS Report RL33898, *Climate Change: The Role of the U.S. Agriculture Sector,* and CRS Report RL31432, *Carbon Sequestration in Forests*.

Current Estimates of Aggregate Mitigation Potential

Estimates of additional carbon storage potential by practice (**Table 2**) underlie USDA and EPA estimates of the annual additional carbon storage potential for various agricultural and forestry activities (**Table 3**). These aggregate estimates are in addition to current estimated sequestration rates in these sectors (**Table 1**).

Table 3. Estimated Sequestration Potential in Aggregate, Annual Tonnage: Net Emission Reductions Below Baseline at a Range of Carbon Prices

(million metric tons of sequestered CO_2)

Source	$3-$5 $/MTCO$_2$-Eq.	$13-$15 $/MTCO$_2$-Eq.	$30-$34 $/MTCO$_2$-Eq.
USDA study			
Afforestation	0 - 31	105 - 264	224 - 489
Agriculture Soil Carbon	0 - 4	3 - 30	13 - 95
Subtotal	0 - 35	108 - 295	237 - 587
EPA study			
Afforestation	12	228	806
Agriculture Soil Carbon	149	204	187
Subtotal	161	432	994

Source: As reported by EPA, *Greenhouse Gas Mitigation Potential in U.S. Forestry and Agriculture*, Table 4-10, Nov. 2005, http://www.epa.gov/sequestration/greenhouse_gas.html. Estimates are for the year 2025.

Notes: Uses comparable estimates from USDA, *Economics of Sequestering Carbon in the U.S. Agricultural Sector*, Apr. 2004, http://www.ers.usda.gov/publications/tb1909/. Net reduction below baseline at a range of carbon prices (about $3- $30/MT CO_2-Eq.). Carbon price levels are in dollars per metric ton of sequestered CO_2 equivalent ($/MT CO_2-Eq.) and reflect the assumed payment for carbon credits in the marketplace under varying scenarios. Estimates shown are annualized assuming a 15-year program.

Both the USDA and EPA studies estimated GHG mitigation potential using market optimization models and available data to simulate net changes in carbon sequestration from adopting certain types of agricultural and forestry practices, compared to current baseline conditions. The text box below provides a brief summary of each study's estimation model and approach. These estimates are reported across a range of assumed carbon market prices. Both studies account for current conditions, as well as expected direct costs and opportunity costs in modeling landowners' decision-making. These estimates are measured in terms of carbon storage over time (15 to 100 years) across a range of assumed carbon market prices (roughly $3 to $50/MT CO_2-Eq.). These published results show a range of carbon prices by type of farming and forestry activity. The presumed relationship between carbon sequestration and price shows that as carbon prices rise, this will likely attract more investment and adoption of additional and differing types of mitigation activities. These estimates are reported as a national total and are also broken out by select U.S. regions. For more information on these models and for additional modeling results, see the EPA and USDA studies.

Overview of USDA and EPA Models

USDA: The USDA study uses an adapted version of the U.S. Agricultural Sector Model (USMP), a spatial market equilibrium model that depicts the U.S. farm sector by geography, crop production, farm-inputs, and production-enterprise. The model uses recognized parameters of cropland and forestry management and conversion, and simulates changes across a range of prices over a 15-year carbon storage program. Examined practices include afforesting croplands and pasture, shifting cropland to permanent grasses, and increasing the use of production practices, such as no-till and rotations that raise soil-carbon levels.

EPA: The EPA study uses the Forest and Agriculture Sector Optimization Model with Greenhouse Gases (FASOMGHG), a partial equilibrium model of the U.S. forest and agriculture sectors that depicts land use competition between the sectors and linkages to international trade, and tracks multiple forest product categories and production possibilities for field crops, livestock, and biofuels for private lands (excluding public lands). The model simulates changes across a range of prices over a 100-year period from afforestation, forest management, changes in tillage practices, energy substitution, livestock management and fertilizer applications, and biofuel offsets of fossil fuels derived from crops.

Table 3 compares the estimated carbon mitigation potential reported by EPA and USDA for two mitigation categories—afforestation and soil carbon sequestration—across a range of assumed carbon prices.[8] Afforestation refers to the creation of forested areas mostly through conversion of pastureland and cropland. Soil carbon sequestration generally refers to cropland management practices, such as conservation or no-till practices, that preserve soil carbon by maintaining a ground cover after planting and by reducing soil disturbance compared with traditional cultivation. Soil sequestration activities reduce the carbon emissions that would otherwise be released to the atmosphere during more traditional cropping practices.[9] Most mitigation studies report the mitigation potential for afforestation and soil carbon sequestration activities, as these have been among the two agriculture and forestry categories associated with the most opportunity for emission mitigation, by volume of carbon stored.

These and other studies examine the mitigation potential from various other farmland and manure management practices, but these categories are generally estimated to contribute a smaller share of overall estimated mitigation potential. However, EPA's study included other major mitigation activities not examined by USDA, such as forest management projects on privately owned lands, fossil fuel substitution, manure management, and other practices.[10]

Both USDA and EPA reported that the agriculture and forestry activities offered the potential to substantially increase sequestration above its baseline. USDA's 2004 study reported projections of an additional mitigation potential of about 240 to 590 MMT CO_2-Eq. annually, assuming a high-end value or market price for carbon.[11] EPA's 2005 study reported even greater additional mitigation potential of about 990 MMT CO_2-Eq. annually, thus increasing to roughly double

[8] In general, the low end of this price range indicates that carbon sequestration potential is mostly associated with cropland management practices, whereas higher-end carbon prices are mostly associated with land retirement and conversion, and a longer sequestration tenure.

[9] See CRS Report RL33898, *Climate Change: The Role of the U.S. Agriculture Sector*.

[10] Ibid, Table 4-5 (100-year time frame). Including these practices, EPA projects these other practices could add another 150 to 830 MMT CO_2-Eq. in annual mitigation, much of which would accrue over the longer term (annualized over 100-years). As discussed in the **Appendix**, estimates of mitigation due to a reduction in fossil fuel use from increased biofuels may now be limited, given changes in national energy policies since the EPA study was completed.

[11] Net reduction below baseline at a range of carbon prices from about \$3 to \$30/MT CO_2-Eq., annualized assuming a 15-year program.

current levels, assuming a high-end market price for carbon.[12] At lower carbon prices, estimated additional mitigation potential was lower, but could still add about 40 to 160 MMT CO_2-Eq. annually above baseline sequestration levels, as estimated across USDA's and EPA's studies.[13]

Some see USDA and EPA estimates of mitigation potential from the agriculture and forestry sectors as an approximation of the potential volume of carbon offsets that might be available for compliance purposes in a cap-and-trade program.[14] As illustrated in these results, both USDA and EPA report that afforestation represents perhaps the greatest potential for carbon uptake among these examined activities, with agricultural soil carbon activities accounting for an overall smaller but still sizeable share of the estimated mitigation potential in some cases (**Table 3**). However, there are important differences in the results of these two studies. As shown in **Table 3**, USDA's 2004 projections were much lower than those projected by EPA for both afforestation and agricultural soil carbon activities. These difference points to potentially very different modeling assumptions between these studies. USDA's lower overall estimate for soil management activities is comparable to other more recent independent estimates.[15]

What these mitigation studies clearly illustrate is that land availability is perhaps the most critical factor for farm and forestry offset projects. Generally, a wider range of offset project types becomes economically competitive at higher carbon prices. At certain price levels, one offset type may replace another. At lower carbon prices, agricultural soil sequestration projects (e.g., conservation tillage practices) are expected to provide the most cost-effective opportunities. At higher prices, afforestation projects may become more cost-effective, depending on how much more carbon is sequestered per acre compared to soil management practices. In theory, as depicted by these models, lands that once sequestered carbon through soil management practices could be replaced with afforestation projects (tree farms) at high carbon prices. However, these practices are expected to be feasible only at higher price levels. Given constraints on land availability and the myriad other market and nonmarket factors influencing land use, these types of considerations are nearly impossible to model and predict with any certainty, making any general conclusions derived from these models subject to a degree of skepticism.

In general, estimated mitigation potential varies significantly across the different studies. This is illustrated in two graphs compiled by the Congressional Budget Office (CBO), showing a wide range of reported estimates of the mitigation potential from afforestation and cropland soil sequestration (**Figure 1** and **Figure 2**).[16] These graphs also illustrate that, over time, estimates of the carbon mitigation potential from agriculture and forestry practices are lower compared to previous estimates, as researchers further refine their simulation models and modeling assumptions and underlying data.

[12] Reported by EPA, *Greenhouse Gas Mitigation Potential in U.S. Forestry and Agriculture*, Nov. 2005, Tables 4-10 (15-year), http://www.epa.gov/sequestration/greenhouse_gas.html. The resultant estimates may overlap between the afforestation and forest management categories.

[13] Although direct comparisons can often be problematic, the comparison of the two studies has been largely standardized across both studies (as reported by EPA) to the extent practicable.

[14] Most of the recent cap-and-trade proposals would allow covered entities to submit offsets in lieu of emission allowances (or permits) to satisfy compliance obligations.

[15] For example, see B. McCarl, "Agriculture in the Climate Change and Energy Price Squeeze: Part 2: Mitigation Opportunities," Feb. 2007, http://www-agecon.ag.ohio-state.edu/resources/docs/BruceMcCarlPaper.pdf.

[16] CBO, *The Potential for Carbon Sequestration in the United States*, Sept. 2007, Figures 1 and 2, http://www.cbo.gov/ftpdocs/86xx/doc8624/09-12-CarbonSequestration.pdf. The reduction in sequestration at higher CO_2 prices reflects the fact that alternative uses of land (such as for growing biofuel crops) become more cost-effective at higher CO_2 prices.

Figure 1. CBO Estimates of the Amount of Carbon That Would Be Sequestered Annually Through Afforestation in the United States at Different CO_2 Prices

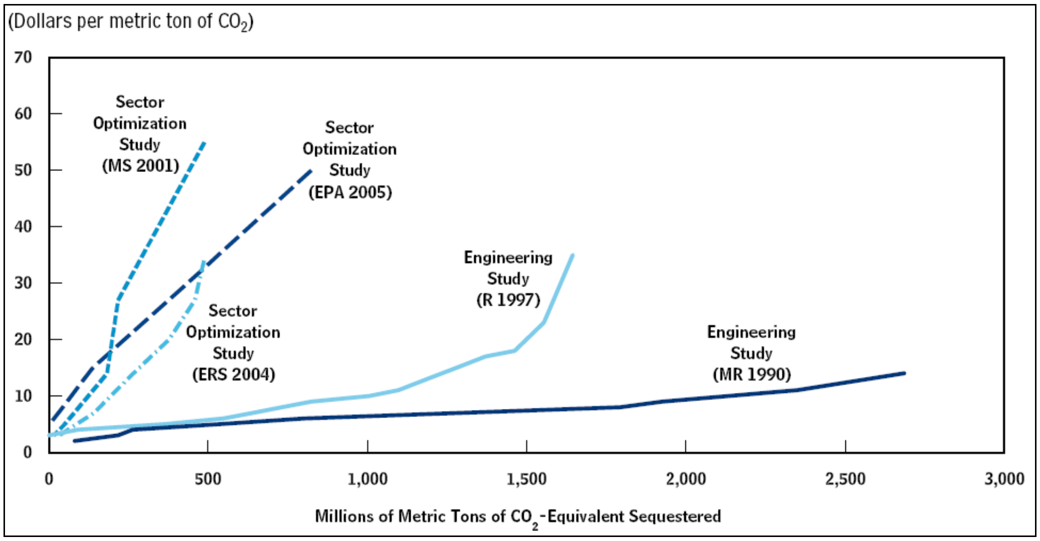
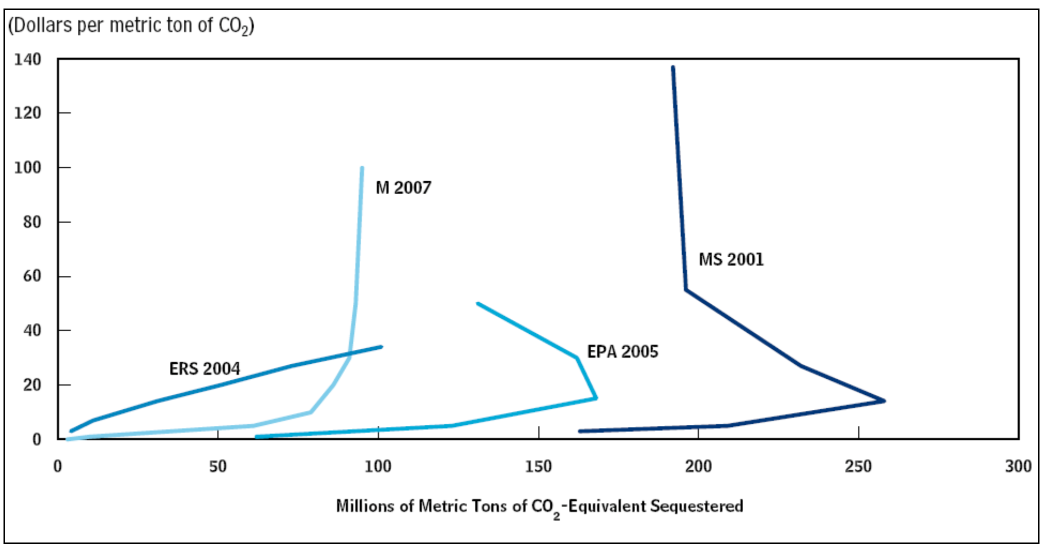


Figure 2. CBO Estimates of the Amount of Carbon That Would Be Sequestered Annually In Cropland Soil in the United States at Different CO_2 Prices



Source: Congressional Budget Office (CBO), *The Potential for Carbon Sequestration in the United States*, Sept. 2007, Figure 2, http://www.cbo.gov/ftpdocs/86xx/doc8624/09-12-CarbonSequestration.pdf. The reduction in sequestration at higher CO_2 prices reflects the fact that alternative uses of land (such as for growing biofuel crops) become more cost-effective at higher CO_2 prices.

Notes: EPA 2005 = EPA, *Greenhouse Gas Mitigation Potential in U.S. Forestry and Agriculture*, November 2005. ERS 2004 = USDA, *Economics of Sequestering Carbon in the U.S. Agricultural Sector*, Apr. 2004. MS 2001 = Bruce A. McCarl and Uwe A. Schneider, "Greenhouse Gas Mitigation in U.S. Agriculture and Forestry," *Science*, vol. 294 (December 21, 2001), pp. 2481–2482. R 1997 = Kenneth R. Richards, *Estimating Costs of Carbon Sequestration for a United States Greenhouse Gas Policy* (Boston: Charles River Associates, 1997). MR 1990 = Robert J. Moulton and Kenneth R. Richards, *Costs of Sequestering Carbon Through Tree Planting and Forest Management in the United States*, General Technical Report WO-58 (USDA, Forest Service, 1990). M 2007 = Bruce A. McCarl, "Agriculture in the Climate Change and Energy Price Squeeze, Part 2: Mitigation Opportunities" (presentation given at the 4th USDA Greenhouse Gas Conference, Feb. 6-8, 2007).

USDA and EPA study results provide a breakdown of these aggregate estimates by selected U.S. regions. USDA predicts that the greatest mitigation potential is in areas with potential for enhancing afforested croplands (Appalachian, Southeast, and Pacific regions), although at lower mitigation levels, mitigation from soil management is expected in areas where crop production is greatest (Lake States, Corn Belt, and Delta regions). EPA's results are similar, albeit across differently named U.S. regions: mitigation potential is greatest in areas with potential for afforestation activities (South Central and Southeast) and also for soil management in crop-producing regions (Corn Belt, Lake States, and Plains States). Consistent with the national results, gains in mitigation are greatest at carbon prices exceeding \$30/MT CO_2-Eq.

Estimated Current versus Potential Additional Mitigation

Comparing estimated current carbon sequestration levels with projected future mitigation potential is problematic. These projections are highly uncertain and dependent on the simplifying assumptions and data used to model them, in an attempt to simulate possible future conditions. Actual mitigation potential will ultimately depend on how an emissions trading program allows farm and forestry carbon offsets to be defined and measured, what the program allows as offsets, and the ultimate carbon price.

Compared to current estimated mitigation potential levels, USDA and EPA projections provide a mostly positive picture of the potential for farm and forestry activities to mitigate GHG emissions. Current estimates of the amount of carbon sequestered by both the agricultural and forestry sectors are more than 1,100 MMT CO_2-Eq. per year (**Table 1**). Estimates by USDA and EPA reported in 2004-2005 project an added mitigation potential of 590 to 990 MMT CO_2-Eq. annually, thus increasing to roughly double the current levels (assuming the high end of the price range and a 15-year program). At lower prices, estimated additional mitigation potential is lower, adding about 40 to 160 MMT CO_2-Eq. annually above current sequestration levels (**Table 3**).

As discussed in the section titled "Comparison of EPA's 2005 and 2009 Modeling Results," more recent EPA estimates are lower than those reported by the agency in 2005 for certain mitigation activities.

Limitations of Mitigation Potential Estimates

The results of the USDA and EPA studies provide a useful tool for evaluating the additional mitigation potential of the farm and forestry sectors. However, given the inherent limitations of any modeling approach, these results need to be considered with careful qualification.

Following the publication of these mitigation studies, various prominent researchers criticized the model simulations and the modeling results, reporting that the estimates for various agriculture and forestry mitigation activities were likely overstated.[17] Aside from general caveats about the limitations of using simulation models to illustrate highly complex spatial and temporal dynamics, interrelationships, and processes, these criticisms focused on recent market changes, shifts to biofuel feedstocks, land availability, and renewable biofuels requirements, among other

[17] See, e.g., Duke University, Nicholas Institute for Environmental Policy Solutions, *Designing Offsets Policy for the U.S. Principles*, May 2008, http://www.env.duke.edu/institute/offsetspolicy.pdf.

things. As a result, some researchers believe that many of the underlying data and simplifying assumptions of the EPA and USDA simulation models may no longer be valid, making the resultant estimates of these studies outdated. Reasons for these concerns include:

- USDA and EPA analyses were completed before the enactment of the Energy Policy Act of 2005 and the Energy Independence and Security Act (EISA) of 2007 and thus do not include the effects of the Renewable Fuel Standard (RFS).[18]
- USDA and EPA analyses were developed using data and assumptions of farm production prior to 2003 and do not include the effects of increasing federal support for farm-based bioenergy production in subsequent omnibus farm bills.
- EPA and USDA models were developed following a period of generally declining agricultural prices, stable net farm income, and a reduction in land devoted to agricultural production, which are the assumed market conditions that form the basis for depicting future conditions and mitigation potential.
- Aspects of the EPA's model simulations of the forestry sector have been disputed, including questions about the validity of estimates of the carbon offset potential of forest projects, uncertainty about the causes of land use changes, and concerns about the validity of forest carbon offset projects since climate change may be affecting forests.
- EPA and USDA models are limited in that they might not accurately reflect conditions of mitigation potential depending, in part, on how Congress ultimately designs its emissions trading scheme and carbon offset program (e.g., how Congress will specify in terms of the underlying requirements and protocols for any participating sector designated as a supplier of carbon offsets, and also how the program is ultimately implemented).

A detailed summary of these criticisms and concerns is provided in the **Appendix**.

Changes to EPA's Simulation Models and Results

In March 2009, EPA announced it had updated its underlying model and its estimates of the carbon mitigation potential from farm and forestry practices. As noted, previous EPA estimates for mitigation from agriculture soil carbon activities were questionably higher than USDA's own estimates. Also, both EPA's and USDA's models were being criticized for having been conducted using potentially outdated data and modeling assumptions. It is not clear whether USDA is considering changes and updates to its simulation model and analysis, similar to EPA.

Comparison of EPA's 2005 and 2009 Modeling Results

The recent changes to EPA's simulation models have implications for the agency's analysis of the overall estimated mitigation potential from agriculture and forestry activities. These differences are reflected in modeling results presented in EPA's March 2009 memorandum (**Figure 3**),[19] as

[18] Energy Policy Act of 2005 (P.L. 109-58, Sec. 203); Energy Independence and Security Act of 2007 (P.L. 110-140, Title II, Subtitle A).

[19] See EPA memorandum, "Updated Forestry and Agriculture Marginal Abatement Cost Curves," March 31, 2009.

well as in the separate analysis conducted by EPA in the April 2009 analysis of the mitigation potential of the leading House climate bill, H.R. 2454 (results not presented here).[20] As estimated by EPA, for some mitigation activities, underlying changes to EPA's models translate into significant differences compared to previous EPA estimates.

EPA's revised estimates, presented in bar chart form in **Figure 3**,[21] can be roughly compared with EPA's previous 2005 estimates for selected mitigation categories (**Table 3**).[22] (At this time, comparable estimates are not available to strictly compare EPA's numerical estimates presented in **Table 1**.) Of particular concern to many in the U.S. agriculture sector, EPA's current estimates of the mitigation potential from agriculture soil carbon activities—such as conservation or no-till practices that preserve soil carbon—are sharply lower (**Figure 3**) than those of 2005. Given the available information, EPA's 2005 analysis projected that agriculture soil carbon activities would provide about 150-200 MMT CO_2-Eq. of carbon mitigation in 2025 (across a range of prices of about \$3-\$30/MT CO_2-Eq.,**Table 3**). EPA's current 2009 analysis shows that, at lower carbon prices, agriculture soil carbon activities are negligible, and at higher prices agriculture soil carbon activities account for a smaller share of overall mitigation activities than previously estimated.

Estimates from EPA's 2005 and 2009 models might not be strictly comparable because of differences in the underlying models, and assumptions regarding carbon prices and the relevant time horizons, among other factors.[23] However, given the available information, it is clear that EPA's revised 2009 projections are significantly lower than EPA's 2005 estimates. EPA's revised 2009 estimates range from zero to roughly 20 MMT CO_2-Eq. per year across the range of prices. At the higher carbon price level of about \$30/MT CO_2-Eq., the revised 2009 estimates are roughly 20 MMT CO_2-Eq., compared to EPA's 2005 estimate of about 200 MMT CO_2-Eq. in 2025, or only as much as 10% of EPA's previous projections.[24] EPA's revised estimate for agriculture soil carbon activities is also considerably lower than USDA's 2004 estimates, which were reported to range from about 10 to less than 100 MMT CO_2-Eq. of carbon mitigation in 2025 (at a carbon price of about \$30/MT CO_2-Eq., **Table 3**). The revised EPA estimates are substantially lower than USDA's 2004 estimate for agriculture soil carbon activities.

As a share of total potential mitigation in the later years, EPA's revised estimate for agriculture soil carbon activities dropped from about 15% of the projected mitigation potential from all agricultural and forestry activities to less than 2%.[25] The projected mitigation potential from other mitigation activities, such as forest, manure, and crop management, are generally greater than was previously estimated by EPA.

[20] EPA, "Waxman-Markey Discussion Draft Preliminary Analysis: EPA Preliminary Analysis of the American Clean Energy and Security Act of 2009," Appendix, http://epa.gov/climatechange/economics/pdfs/WM-Appendix.pdf. See slides 25-27 for agriculture and forestry results. Other information is at http://epa.gov/climatechange/economics/economicanalyses.html#wax.

[21] See EPA memorandum, "Updated Forestry and Agriculture Marginal Abatement Cost Curves," March 31, 2009.

[22] EPA, *Greenhouse Gas Mitigation Potential in U.S. Forestry and Agriculture*, Nov. 2005, Table 4-10, at http://www.epa.gov/sequestration/greenhouse_gas.html.

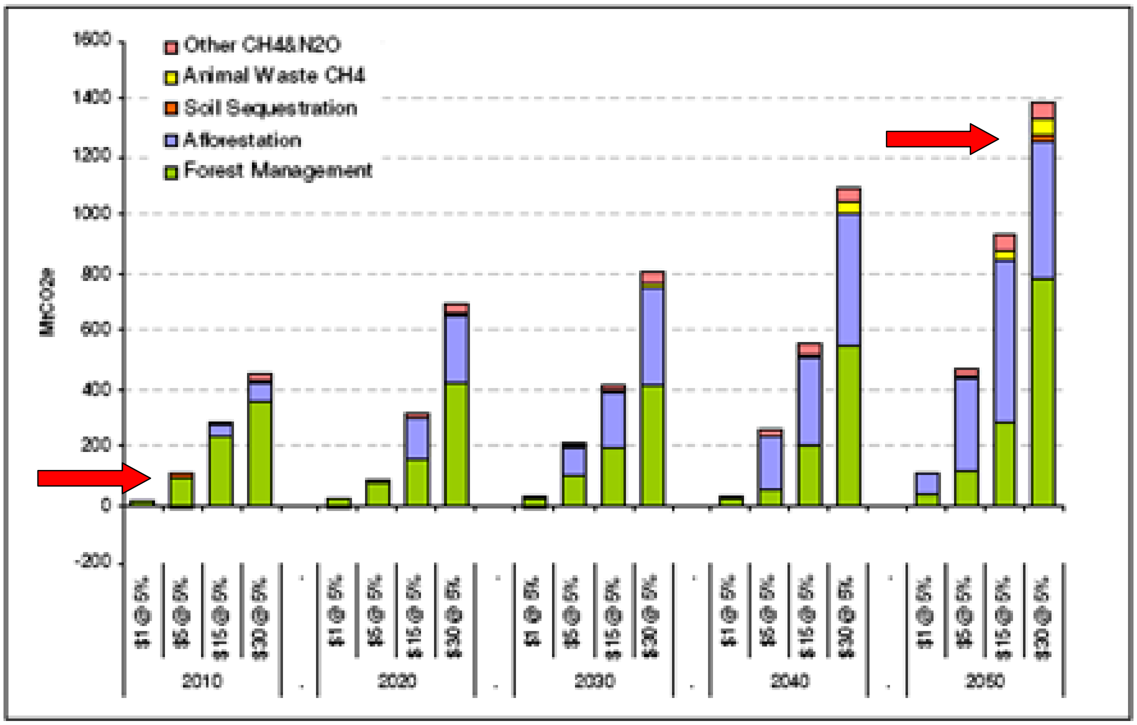
[23] For several reasons, it is problematic to compare estimates across various estimates. See CRS Report RL34705, *Potential Offset Supply in a Cap-and-Trade Program.*

[24] Based on estimates shown in **Figure 3** and also EPA's data files, "Category: Domestic agriculture, forestry, and biofuel, rising carbon prices," available at http://epa.gov/climatechange/economics/economicanalyses.html#wax.

[25] EPA's estimate of the total mitigation potential from agriculture and forestry activities is more or less unchanged (assuming a \$30/MT carbon price) at roughly 1,400 MMT CO_2-Eq. annualized over the time period from 2010-2110.

Figure 3. EPA Estimates of the Average Offset Marginal Abatement Curves

(by practice, under a rising prices scenario, 2010-2050)



Source: Arrows added by CRS; figure from EPA, "Memorandum: Updated Forestry and Agriculture Marginal Abatement Cost Curves," March 31, 2009.

Notes: The arrows indicate the years and prices (only two instances) at which soil sequestration activities are estimated to occur. At all other times and prices, soil sequestration is zero. In 2010, EPA estimates 9.2 million metric tons of CO_2-equivalent (MMT CO_2-e) will be sequestered at a price of \$5/mtCO_2-e. In 2050, EPA estimates that 22 MMTCO_2-e will be sequestered at a price of \$211/MT CO_2-e (the price reached in 2050, when the price starts at \$30/MT CO_2-e in 2010 and increases by 5% each year).

Differing Baseline Assumptions for Agriculture Soil Activities

Perhaps one reason why EPA's revised 2009 estimates for agriculture soil carbon activities are lower is that EPA's revised model incorporates dramatically lower assumed baseline conditions for agricultural soil activities (**Table 4**). A baseline estimate indicates what EPA expects would be the level of emissions (or sequestration) from a particular emission source/sink (e.g. agricultural soils), in the absence of GHG emission controls, such as a cap-and-trade program. In other words, the baseline represents a business-as-usual (BAU) scenario.

In the 2005 model, EPA projected that agricultural soils would be a net emitter of CO_2, generating 32 MMT CO_2-Eq. in 2010. However, in its 2009 model, EPA estimates that agricultural soils, in aggregate, will provide a net source of sequestration in 2010. The difference between these estimated starting points is 109 MMT CO_2-Eq. in the base year, which, in terms of agricultural soil emissions or sequestration, is relatively large.

Table 4. Comparison of EPA's Baseline Assumptions for Carbon Sequestration from Agricultural Soil Activities

(in million metric tons of CO_2-equivalent)

	2010		2020	
	2005 results	**2009 results**	**2005 results**	**2009 results**
Agricultural soil carbon activities	32	(77)	10	(25)

Source: Prepared by CRS, data from EPA, "Memorandum: Updated Forestry and Agriculture Marginal Abatement Cost Curves," March 31, 2009.

Notes: The positive numbers indicate net emissions; the numbers in parentheses indicate net sequestration.

The EPA memorandum that provided the baseline comparisons did not fully explain why the agency found such a dramatic difference. However, a recent news article cited comments from one of the model's developers, Bruce McCarl of Texas A&M University, indicating that these new estimates reflect the way agriculture has changed in recent years. According to the article, McCarl explained that the 2005 model baseline was based on farm practices from the late 1990s. Since that time, farmers have "reduced their tillage considerably in response to higher fuel prices, and that means much of the potential reduction in carbon emissions that the EPA forecast in 2005 has already been made."[26] The revised baseline for agricultural soils in the 2009 model was likely an important factor in determining the projected offset activity related to soil sequestration. As the revised baseline figure suggests, mitigation practices that involve transitioning U.S. agriculture to conservation tillage practices may provide for lower additional carbon mitigation potential in the future, perhaps because, as USDA reports, many crop producers (estimated at 40% of U.S. croplands in the early 2000s) may already be using these types of tillage practices.

Considerations for Congress

As Congress continues to consider the legislative options for addressing climate change and, more specifically, the role of the agricultural and forestry sectors within this debate, available estimates of GHG mitigation potential provide an indication of the potential for carbon storage in these sectors. Agricultural and forestry activities that store and sequester carbon are likely to be considered by some in Congress for inclusion under a cap-and-trade program.

Some in Congress have taken an unfavorable view of EPA's revised analysis that now shows a reduction in the estimated mitigation potential from agriculture and forestry practices, particularly estimates of sharply lower potential from agriculture soil carbon activities, such as conservation tillage and no-till practices on croplands. At a House Agriculture Committee hearing in June, 2009, Chairman Peterson and others in the committee commented that given this estimated reduction, the U.S. agriculture sectors might have less of an incentive to support climate change legislation, since these modeling results show potentially lower opportunities for the agriculture sectors to benefit under a carbon reduction program.[27]

[26] Philip Brasher, "Big cut in emission credits could hinder climate bill," June 9, 2009, *Des Moines Register Online,* http://www.desmoinesregister.com.

[27] See, for example, opening comments and questions by Chairman Peterson of the House Committee on Agriculture at a full committee hearing, "To review pending climate legislation," June 11, 2009.

Appendix. Criticisms of Existing Simulation Models, Data, and Assumptions

Following is a detailed summary of the concerns by various prominent researchers who have criticized existing model simulations and the modeling results, including reports by USDA and EPA. This includes a detailed discussion covering general caveats about the use of simulation models, recent legislative and market changes, shifts to biofuel feedstocks, land availability, and renewable biofuels requirements, among other issues.

General Caveat on Market Models

All simulation models are theoretical constructs intended to represent a system or group of functionally interrelated elements forming a complex whole. At best, simulation models provide for a simplified framework designed to illustrate highly complex spatial and temporal dynamics, interrelationships, and processes. They depend highly on available data and, inevitably, on the simplifying assumptions of the models necessary to depict the underlying relationships and processes of a complex system. This complexity can be attributed to a number of factors that are difficult to quantify, including resource limitations, environmental and geographical constraints, site-specific conditions, individual and cooperative decision processes, institutional and legal requirements, and general uncertainty and variability. Consequently models must often rely on overly simplistic assumptions, such as perfect market competition or optimum behavioral outcomes (e.g., assuming that all farmers and landowners act in a prescribed manner, and follow required protocols and manage their operations in ways that achieve maximum on-site carbon sequestration). Thus, simulation models are limited in the extent to which they are able to reflect actual conditions accurately. Moreover, it is difficult to compare the results of various studies, given differences in modeling approach and methodology, scope (geographic region, commodity sector activities, assumptions about adoption of certain mitigation strategies, etc.), and other underlying assumptions.

In addition, available estimates have notable limitations, given certain policy and market conditions that have occurred since these simulation models were developed. For example, in the past few years, the agricultural and forestry sectors have been affected by major changes in federal energy and farm policy, coupled with ongoing market changes, such as rising farmland values, rising farm input costs, crop and consumer price volatility, and competition for land and shifting land uses. These policy and market changes have in turn influenced farm and landowner decisions regarding agricultural production, forest management, and land use. As a result, some researchers believe that many of the underlying data and simplifying assumptions of these simulation models may no longer be valid, making the resultant estimates of these studies outdated.[28]

[28] See, e.g., Duke University, Nicholas Institute for Environmental Policy Solutions, *Designing Offsets Policy for the U.S. Principles*, May 2008, http://www.env.duke.edu/institute/offsetspolicy.pdf.

National Energy Policy Provisions[29]

USDA and EPA analyses were completed before the enactment of the Energy Policy Act of 2005 and the Energy Independence and Security Act (EISA) of 2007 and thus do not include the effects of the Renewable Fuel Standard (RFS).[30]

The RFS requires the use of ethanol and other renewable fuels in transportation fuels. Specifically, the current RFS requires the use of 9 billion gallons of renewable fuel in 2008, increasing to 36 billion gallons in 2022. A large share of this mandate is currently being met using corn-based ethanol. However, EISA requires that a growing share of the mandate—21 billion gallons in 2022—be met using “advanced biofuels,” which are produced from feedstocks other than corn starch. Advanced biofuels will likely include imported ethanol produced from sugar cane and gasoline and diesel substitutes produced from cellulosic materials such as perennial grasses and fast-growing trees.

The establishment of the RFS presents two key obstacles in projecting available land for GHG mitigation activities. First, production of feedstocks to meet the RFS will require land that otherwise could have been used for afforestation or other conservation practices. Second, the RFS itself requires that corn-starch ethanol and advanced biofuels have lower lifecycle greenhouse gas emissions than conventional (fossil) fuels. Therefore, any emission reductions resulting from conservation practices used on feedstock-producing lands may be needed for compliance with the RFS. A key component of “additionality” is that for an offset to be valid, the practice being credited would not have been done in the absence of the offset market. Granting an offset in this case would effectively allow producers to double-count their emissions reductions—once to meet the RFS life-cycle standard and once for sale or credit as an offset.

Stated differently, mitigation potential from a reduction in fossil fuel use resulting from an increase in biofuels use can no longer be counted toward the agricultural sector since it would be instead counted by an upstream entity. However, EPA’s study includes mitigation potential from substituting fossil fuel use with biofuels (derived from bioenergy crops such as switchgrass) as part of its aggregate estimates.

Farm-Based Energy Policy Provisions[31]

The USDA and EPA analyses were developed using data and assumptions of farm production prior to 2003 and do not include the effects of increasing federal support for farm-based bioenergy production in subsequent omnibus farm bills. Many of the implications are duplicative of those discussed for the national energy policies, since many of the farm bill’s energy-related policies similarly promote renewable fuels.

Starting with the 2002 farm bill, Congress included an energy title to support farm-based renewable energy production. These policies were expanded in the 2008 farm bill.[32] The 2008

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[29] Brent D. Yacobucci, Specialist in Energy and Environmental Policy (7-9662), contributed to this section of the report.

[30] Energy Policy Act of 2005 (P.L. 109-58, Sec. 203); Energy Independence and Security Act of 2007 (P.L. 110-140, Title II, Subtitle A).

[31] Randy Schnepf, Specialist in Agricultural Policy (7-4277), contributed to this section of the report.

[32] Farm Security and Rural Investment Act of 2002 (P.L. 107-171, Title IX); Food, Conservation, and Energy Act of (continued...)

farm bill contains provisions that coordinate and fund research on biobased energy technologies, provide grants and loans to promote the development of cellulosic biorefinery capacity, and support the development of alternative (non-food) feedstock resources and the infrastructure to process them. Cellulosic feedstocks, such as switchgrass and woody biomass, are given high priority in both research and funding. In addition, tax and trade provisions in the farm bill support corn-starch ethanol and advanced biofuels through tax credits and the continuation of the import tariff for ethanol. These enacted provisions specifically target farm-based energy production, in conjunction with related, broader national policies, and affect estimates of the mitigation potential of farm and forestry offsets, since many of the models and studies were developed and completed before these policies were implemented.

The long-term cumulative impact of farm bill energy provisions and EISA are twofold. First, corn-starch ethanol output will continue expanding rapidly and even more acres will be devoted to cornstarch ethanol until the 15 billion gallon cap in the expanded RFS is reached in 2012.[33] Second, increased production of cellulosic feedstocks could significantly alter land use patterns. Production of cellulosic ethanol—assuming technical advances—likely will expand under the correct set of economic conditions including strong government support (to offset market risk) and a return to high energy prices. However, weak petroleum prices (under $50 per barrel) would jeopardize the profitability of the U.S. ethanol sector and would likely constrain private sector investment in new ethanol production capacity.

Cellulosic feedstocks, such as corn stover, switchgrass, or woody biomass, are residuals of current production or are generally grown on marginal land. Growing these crops for biofuels competes for available land, thus reducing the area available for other types of sequestration practices, such as afforestation or land retirement or conversion. However, the use of perennial crops, such as switchgrass, or fast-growing poplar or willow, will likely result in reduced GHG emissions from croplands compared to growing corn for ethanol, because they need not be planted annually and require fewer inputs.

The bioenergy provisions in omnibus farm and energy bills are expected to continue to influence farm and landowner decision-making. Producers have already demonstrated a strong response to relative price shifts in 2008/2009 that favor corn by expanding corn production to meet ethanol needs, and by shifting acres to corn from crops such as soybeans and wheat. In the 2008/2009 crop marketing year, corn for ethanol is projected to account for 30% of total U.S. corn production.[34] Biofuels policies and energy markets are likely to continue to influence U.S. and global crop production patterns and land use, including decisions regarding land retirement and other conservation-based land conversion (e.g., movement to pasture/range, timberland, and developed uses), as well as various conservation practices. The USDA and EPA simulation models, however, do not take into account these policies nor do they take into account other production-related changes associated with expanding bioenergy production.

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2008 (P.L. 110-246, Title IX).

[33] This is a cap on its application for the RFS. There is no limit on total corn-based production or ethanol tax credits—the only cap is on corn ethanol's role under the mandate.

[34] USDA, World Agricultural Supply and Demand Estimates (WASDE), August 8, 2008.

Agriculture Market Conditions

The simulation models used by EPA and USDA were developed following a period of generally declining agricultural prices, stable net farm income, and a reduction in land devoted to agricultural production. These trends were fed into the simulation model forming the basis for depicting future conditions and mitigation potential. For example, EPA's model was developed taking into account the following market conditions:

> During this period, real agricultural prices (i.e., net of inflation) have trended downward; net farm income has stayed about even; and, as discussed above, land devoted to agriculture has dropped. Increases in agricultural productivity have reduced the amount of land needed for agriculture, leading to land retirement and movement to pasture/range, timberland, or developed uses.[35]

Actual market conditions proved different, however, in part because of policy-induced renewable energy production, as well as because of rapid macroeconomic shifts. In particular, the study's assumption that cropland areas were decreasing was potentially problematic, given recent trends showing that cropland acreage may be rising. Following a period of declines in crop acres from the mid-1990s through 2005, USDA data show that acreage devoted to principal crops increased by 3% from 2006 through 2008. [36] During this same period, corn for use in ethanol production increased from 20% of the crop to 30% in 2008.[37] Long-run commodity price projections from USDA suggest that, when commodity prices return to equilibrium after the spikes of 2007 and 2008, the long-run average price for major program crops will settle at levels significantly above the recent 10-year average. [38] Since 2006, demand for corn for ethanol has contributed to higher crop acres and boosted food commodity prices. Consequently, USDA considered releasing farmers from Conservation Reserve Program contracts for non-erodible land.

During the early years of the modeling simulation, producer incomes also reached record highs, in part reflecting increased demand for corn as an energy source and all other uses. In fact, farm income reached record highs during this period. This was largely attributable to higher commodity prices.[39] These conditions differ markedly from conditions assumed in the EPA and USDA analyses. Alternatively, current economic conditions may significantly depress farm incomes in the near term. USDA projects that 2009 net farm income will be lower than estimates for 2008, but still higher than the average earned in the previous 10 years.[40]

Higher carbon price levels and shifts in underlying competition for resources and land could trigger further market effects. For example, additional pressures on crop production could raise crop and food prices, which in turn could influence farm-level decisions that could counteract intended mitigation efforts (e.g., more intensive and concentrated production, a focus on growing certain crops, or encouraging use of certain inputs, such as chemicals and fertilizers).

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[35] EPA, *Greenhouse Gas Mitigation Potential in U.S. Forestry and Agriculture,* Nov. 2005, pp. 3-17.

[36] USDA, *2008 Acreage Report*, June 2008.

[37] USDA, World Agricultural Supply and Demand Estimates, February 10, 2009.

[38] USDA Office of the Chief Economist, "USDA Agricultural Projections to 2018," OCE-2009-1, February 2009. Compares the 1997/98 and 2006/07 time period.

[39] For more information, see CRS Report R40152, *U.S. Farm Income.*

[40] USDA, "Farm Income and Costs: 2009 Farm Sector Income Forecast," http://www.ers.usda.gov/Briefing/FarmIncome/nationalestimates.htm.

Forestry Sector Uncertainties

Aside from policy and market changes that are affecting land availability for other conservation and mitigation uses, various prominent researchers have criticized the model simulations of the forestry sector within these GHG mitigation studies.

Three aspects of forestry raise significant questions about the validity of the various estimates of the carbon offset potential of forest projects, including afforestation and sustainable forest management. One aspect is the precision of the available tools for measuring forest carbon. The tools—both tables[41] and computer models[42]—use USDA Forest Service inventory data from the Forest Inventory Analysis (FIA) program for annualized or periodic estimates of forest carbon in a wide array of forested ecosystems in various regions of the United States. One analysis noted that "these tools use the best available information, provide ready public access, and several allow for frequent updating using the most recent surveys," and that "these tools are appropriate for coarse-scale comparisons of forest carbon storage across large regions."[43] The analysis goes on to note that the FIA data were developed to measure merchantable timber volume and provide "no direct measurements of many important forest carbon pools."[44] It also states that "available measures cannot reliably estimate year-by-year additions to forest carbon stores, due to estimation errors and data gaps."[45] The authors of various reports estimating forest carbon acknowledge such possible problems:

> In some cases, definitional or procedural changes in collecting the underlying inventory data may cause apparent shifts in carbon stocks. For example, the definitions of forest land or forest type were not applied consistently for some National Forest lands in the West. Reported changes in stocks may be the consequence of such inconsistencies rather than a reflection of actual change in the forest resource.[46]

Another reported inaccuracy is the alleged underestimate of carbon stored in old-growth forests.[47] This criticism is supported by a separate report on old-growth forest carbon, which found that untouched natural forests store three times more CO_2 than previously estimated and 60% more than replanted forests.[48] The possible inaccuracies in measuring forest carbon raise significant questions about the accuracy of projections of the results of possible forest carbon sequestration projects.

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[41] See, for example, J. E. Smith, L. S. Heath, K. E. Skog, and R. A. Birdsey, *Methods for Calculating Forest Ecosystem and Harvested Carbon with Standard Estimates for Forest Types of the United States*, Gen. Tech. Rept. NE-343, April 2006), p. 216, http://nrs.fs.fed.us/pubs/8192.

[42] See, for example, J. E. Smith, L. S. Heath, and M. C. Nichols, *U.S. Forest Carbon Calculation Tool: Forest-Land Carbon Stocks and Net Annual Stock Change*, Gen. Tech. Rept. NRS-13, 2007, p. 28, http://nrs.fs.fed.us/pubs/2394; and National Council for Air and Stream Improvement, COLE: Carbon On-Line Estimator, version 2.0, http://ncasi.uml.edu/COLE.

[43] A. Ingerson and W. Loya, *Measuring Forest Carbon: Strengths and Weaknesses of Available Tools*, Science & Policy Brief, April 2008.

[44] Ibid.

[45] Ibid.

[46] R. A. Birdsey and G. M. Lewis, *Carbon in U.S. Forests and Wood Products, 1987-1997: State-by-State Estimates*, Gen. Tech. Rept. NE-310 USDA Forest Service and U.S. EPA, Aug. 2003, http://www.treesearch.fs.fed.us/pubs/5565.

[47] Measuring Forest Carbon, pp. 2, 14-16.

[48] M. Perry, "Untouched Forests Store 3 Times More Carbon: Study," ENN: Environmental News Network, Aug. 4, 2008.

A second aspect of the uncertainty of forest carbon offset potential relates to the causes of land use changes, both increases and decreases in forest acreage. Historically, U.S. forest land area has fluctuated roughly in inverse proportion to agricultural land area—forest lands cleared for agriculture, and to a lesser extent crop or pasture lands abandoned and reverting to forest.[49] Although forest area has been relatively stable since the 1920s, recent years have seen a continued slow loss to development, especially residential and related uses.[50] Both agricultural land area and development have been relatively unaffected by forestry programs. The shift into and out of agricultural production has largely been driven by agricultural policies and programs; for example, tree planting data since 1950 show two significant, temporary increases in area planted—the late 1950s and early 1960s under the Soil Bank Program and the late 1980s and early 1990s under the Conservation Reserve Program.[51]

Thus, projections of potential forest carbon offsets must reflect agricultural programs; estimates made prior to the enactment of the 2008 farm bill and other statutes, with new agricultural bioenergy programs and other incentives to expand (or contract) pasture or crop lands, could substantially overstate (or understate) forestry project potential. In contrast, development pressures are related to population and economic growth, with such factors as interest rates and immigration policies being significant.[52] Thus, the economics of GHG mitigation in the forestry sector are affected by a wide variety of factors, most of which are unrelated to forest policy. Many of these have changed in recent years, and likely will continue to change.

The third aspect that raises questions about the validity of forest carbon offset projects is that climate change is believed to be affecting forests. The existing tools for estimating forest carbon changes all base their estimates on existing or past forest growth. However, climate change is already significantly affecting forest productivity. Some have found that additional atmospheric CO_2 enhances forest growth.[53] Others have reported limitations to growth-stimulating effects of CO_2.[54] Perhaps more significant than these impacts are the changes already seen in wildfire magnitude and frequency and in insect and disease infestations.[55] For example, the government of British Columbia has estimated that 80% of the pine timber in BC's interior forests (40% of all timber) will be dead by 2013 from the current mountain pine beetle infestation.[56] Impacts of this

[49] D. W. MacCleery, *American Forests: A History of Resiliency and Recovery*, FS-540, USDA Forest Service and Forest History Society, 1992, p. 15.

[50] R. J. Alig and A. J. Plantinga, "Future Forestland Area: Impacts From Population Growth and Other Factors That Affect Land Values," *Journal of Forestry*, v. 102, no. 8, Aug. 2004.

[51] R. J. Moulton, "Tree Planting in the United States, 1997," *Tree Planters' Notes*, USDA Forest Service, v. 49, no. 1, 1999, p. 6.

[52] R. Alig, "Land-Base Changes in the United States: Long-Term Assessments of Forest Land Condition," Proceedings of the Sixth Annual Forest Inventory and Analysis Symposium (Denver, CO, Sept. 21-24, 2004), Gen. Tech. Rept. WO-70, USDA Forest Service, 2006, pp. 9-19.

[53] D. T. Tissue, R. B. Thomas, and B. R. Strain, "Atmospheric CO_2 Enrichment Increases Growth and Photosynthesis of Pinus taeda: A 4 Year Experiment in the Field," Plant, *Cell, and Environment*, v. 20, no. 9, Sept. 1997, pp. 1123-1134.

[54] A. C. Finzi, D. J. P. Moore, E. H. DeLucia, J. Lichter, K. S. Hofmockel, R. B. Jackson, H. Kim, R. Matamala, H. R. McCarthy, R. Oren, J. S. Pippen, and W. H. Schlesinger, "Progressive Nitrogen Limitation of Ecosystem Processes Under Elevated CO_2 in a Warm-Temperate Forest," *Ecology*, v. 87, no. 1, 2006, pp. 15-25.

[55] Respectively, see National Wildlife Federation, *Increased Risk of Catastrophic Wildfires: Global Warming's Wake-Up Call for the Western United States*, 2008, http://www.nwf.org/extremeweather/pdfs/NWF_WildfiresFinal.pdf; and J.A. Logan and J.A. Powell, "Ecological Consequences of Climate Change Altered Forest Insect Disturbance Regimes," *Climate Change in Western North America: Evidence and Environmental Effects*, F.H. Wagner, ed.

[56] British Columbia's Mountain Pine Beetle Action Plan, 2006-2011, http://www.for.gov.bc.ca/hfp/
(continued...)

magnitude raise serious questions about the reliability of projections of potential forest carbon offsets based on historic ecological patterns and productivity.

Regulatory Framework and Future GHG Policies/Programs

Finally, these simulation models are limited in that they might not accurately reflect conditions of mitigation potential depending, in part, on how Congress ultimately designs its emissions trading scheme. Regarding the role of the agriculture and forestry sectors, it is unclear what Congress will specify in terms of the underlying requirements and protocols for any participating sector designated as a supplier of carbon offsets, and also how the regulatory agencies will ultimately implement the overall program.

With respect to estimates of mitigation potential in the agricultural and forestry sectors, CBO states the following caveat:

> [These modeling estimates] do not reflect the effects of whatever regulatory system might be used to implement CO_2 pricing for biological sequestration. Such regulation would probably be relatively complex. To be effective, it would have to address the fact that biological sequestration is not necessarily permanent. And it would need to take into account that biological sequestration measures used on one piece of land could influence the use of other land in ways that could increase greenhouse-gas emissions. Moreover, in measuring biological sequestration for compensation purposes, regulators would have to factor in the amount of sequestration that would have occurred anyway.[57]

Among the types of measurement and implementation issues associated with carbon offsets from farms and forests are concerns about quantification, verification, and monitoring; accounting; permanence; leakage; and additionality.[58] These issues can affect estimates of potential mitigation. For example, USDA's researchers readily acknowledge the potential for "upward bias" in their reported estimates because the models are limited in its treatments of permanence, carbon-stock equilibrium, and leakage.[59] For a discussion of these regulatory and implementation issues, see CRS Report RS22964, *Measuring and Monitoring Carbon in the Agricultural and Forestry Sectors*; and CRS Report RL34560, *Forest Carbon Markets: Potential and Drawbacks.*

Accordingly, these simulation models should be viewed as limited in their ability to reflect future conditions based on how Congress ultimately designs a cap-and-trade program, how Congress specifies the program's underlying requirements and protocols for any participating sector, and how the regulatory agencies implement the program. These issues begin to delve into areas more suited to a discussion of carbon offsets within an emissions trading program. Given the often intractable concerns surrounding the use of carbon offsets, some of the regional and state GHG programs (e.g., RGGI and Western Climate Initiative, and California's statute) are opting for a

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(...continued)

mountain_pine_beetle/actionplan/2006/Beetle_Action_Plan.pdf.

[57] CBO, *The Potential for Carbon Sequestration in the United States*, Sept. 2007, p.8, http://www.cbo.gov/ftpdocs/86xx/doc8624/09-12-CarbonSequestration.pdf.

[58] For more detailed information on these types of concerns, see CRS Report RS22964, *Measuring and Monitoring Carbon in the Agricultural and Forestry Sectors.*

[59] USDA, *Economics of Sequestering Carbon in the U.S. Agricultural Sector*, April 2004, http://www.ers.usda.gov/publications/tb1909/.

narrower set of offset types, such as avoided emissions from livestock manure management systems and on-farm diesel engines, in part to bypass most programmatic concerns about quantifying, monitoring, and verifying carbon offsets from farms and forests.

With respect to the role of carbon offsets within an emissions trading system, various programmatic design and implementation elements could affect offset supply in several ways, from the overall structure of the cap and of program scope (e.g., which sources are covered) to specific logistical details (e.g., monitoring and measuring protocols). The supply of offsets will also be beset by similar issues of competition for resources and land, and questions about how to treat biofuels, among other constraints.

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