CLIMATE LEADERS GREENHOUSE GAS INVENTORY PROTOCOL OFFSET PROJECT METHODOLOGY

for

Project Type: Reforestation/Afforestation

Climate Protection Partnerships Division/Climate Change Division
Office of Atmospheric Programs
U.S. Environmental Protection Agency

August 2008
Version 1.3

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***Climate Leaders** is an EPA industry-government partnership that works with companies to develop comprehensive climate change strategies. Partner companies commit to reducing their impact on the global environment by setting aggressive greenhouse gas reduction goals and annually reporting their progress to EPA.*

Introduction

An important objective of the Climate Leaders program is to focus corporate attention on achieving cost-effective greenhouse gas (GHG) reductions within the boundary of the organization (i.e., internal projects and reductions). Partners may also use reductions and/or removals which occur outside their organizational boundary (i.e., external reductions or “offsets”) to help them achieve their goals. To ensure that the GHG emission reductions from offsets are credible, Partners must ensure that the reductions meet four key accounting principles:

- ***Real:*** The quantified GHG reductions must represent actual emission reductions that have already occurred.
- ***Additional:*** The GHG reductions must be surplus to regulation and beyond what would have happened in the absence of the project or in a business-as-usual scenario based on a performance standard methodology.
- ***Permanent:*** The GHG reductions must be permanent or have guarantees to ensure that any losses are replaced in the future.
- ***Verifiable:*** The GHG reductions must result from projects whose performance can be readily and accurately quantified, monitored and verified.

This paper provides a performance standard-based accounting methodology for greenhouse gas (GHG) offset projects that introduce forest planting on cropland or pasture. Quantification can be thought of in two steps: (1) gross effects of carbon sequestered in a forested stand, and (2) adjustments to the gross effects to account for baseline GHG effects that would occur without the project and any emissions leakage generated outside the project boundaries. The former and latter are combined to estimate the net GHG effects of the project.

In order to simplify the quantification process, the *Reforestation Afforestation Project Carbon On-Line Estimator* (RAPCOE) has been produced. RAPCOE is a web-enabled tool based on the quantification methodology described in this paper. This tool was developed by Duke University/Stratus Inc. under contract to, and with technical guidance from, USEPA's Climate Change Division. The link to RAPCOE is available along with this methodology at:
http://www.epa.gov/climateleaders/resources/optional.html#offset.

Program design issues (e.g., project lifetime, project start date) are not within the scope of this guidance and are addressed in the Climate Leaders offset program overview document: Using Offsets to Help Climate Leaders Achieve Their GHG Reduction Goals.[1]

The underlying premise of reforestation/afforestation as a climate change mitigation strategy is that forests remove more carbon dioxide (CO_2) from the atmosphere, storing it in carbon pools, than do alternative land uses such as agriculture. Carbon is sequestered in growing trees, principally as wood in the tree bole. Accrual in forest ecosystems, however, also depends on the accumulation of carbon in dead wood, litter, and soil organic matter.

Description of Project

This methodology applies to afforestation and reforestation projects in the United States. Afforestation is defined by the IPCC as "planting of new forests on lands which, historically, have not contained forests" (IPCC 2000). This practice of afforestation refers specifically to the conversion of pasture, croplands, orchards, or abandoned/barren land into forest. Reforestation is defined by the IPCC as "the establishment of trees on land that has been cleared of forest within the relatively recent past."

Reforestation/afforestation projects increase carbon sequestration of cropland and/or pasture lands because the land transitions to a vegetative structure of higher carbon storage potential than the previous uses. Carbon accumulates in forest biomass, including aboveground components (stems, branches, and leaves) as well as belowground, in the roots. Carbon also accumulates in three other forest ecosystem carbon pools: deadwood, litter, and soil. The rates of carbon accumulation in each of the pools depends on the tree species planted as part of the project, as well as climate, soil type, and management regime.

The following section provides information on the general parameters that a proposed reforestation/afforestation project must match to use this performance standard.

Technology/ Practice Introduced. This guidance document addresses both afforestation and reforestation of **privately-owned cropland or pasture[2]**. Afforestation is often distinguished from reforestation, by implying that the former requires that land should have been in non-forest use for an extended period of time before the planting of trees on the land. For example, under the United Nations Framework Convention on Climate Change, for the purposes of the Kyoto Protocol, this period of time is at least 50 years. There is, however, no single accepted definition of how long the land must remain out of forest to qualify as afforestation rather than reforestation. Because there is no clear time horizon distinction and there is no

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[1] Please visit http://www.epa.gov/climateleaders/resources/optional-module.html to download the overview document.

[2] "Pasture" includes land in managed pasture and rangeland for grazing.

significant difference between forest carbon yields of afforestation versus reforestation projects, this methodology does not require a specific distinction between these two offset project types.

It is of importance to note that elsewhere, reforestation also commonly alludes to regeneration of land immediately or soon after harvest. In other words, reforestation defined in those terms does not involve a land use change. This guidance document, however, applies to reforestation that, by definition, does result in a land use change: from cropland or pasture to forest. The alternative definition of regeneration as reforestation will be captured in the EPA recommended forest management offset methodology (in preparation).

For this methodology, we thereby define both afforestation and reforestation as the planting of trees on private cropland or pastureland that causes the land to change from non-forest to forest use.

Project Size/Output. This accounting methodology applies to any reforestation/afforestation project regardless of size. The project size will generally be designated according to land area (acres or hectares) or amount (tonnes or "metric tons") of carbon sequestered. Project size is determined by the landowner and project developer.

Location/Spatial Area. The methodology described in this paper is applicable for afforestation/reforestation projects across the continental U.S. Because land use trends, forest yields, and other biophysical conditions related to an afforestation/reforestation project vary across the landscape, project quantification methods have been developed with as much regional specificity and spatial refinement as possible.

Project Boundary. This section provides guidance on which physical components, and associated greenhouse gases, must be included in the project boundary for a reforestation/afforestation project.

> **Physical Boundary**. The physical boundary of a project consists of the entire area of land that is converted to forest. Though the project activity may have effects outside of the physical boundary of the project, such as indirect impacts on activities conducted on other landholdings of the owner, these are dealt with as part of the application of a leakage factor.
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> **GHG Accounting Boundary.** The primary GHG of interest for a reforestation/afforestation project is CO_2, which is removed from the atmosphere and stored in the forest ecosystem as carbon via photosynthesis and biogeochemical processes. The methodology and RAPCOE include the following carbon pools: trees (live and standing dead), understory vegetation, down dead

wood, forest floor litter and soil. Ideally, the project accounting should include any non-CO_2 GHG effects from the project as well. For example, under some circumstances, nitrous oxide (N_2O) may be emitted through the use of nitrogenous fertilizers applied to managed forests. There is little data, however, at this time to quantify these effects. This methodology document and the accompanying Reforestation Afforestation Project Carbon On-Line Estimator (RAPCOE) tool, therefore, include only sequestered carbon onsite at this time. The forest ecosystem pools covered are: trees (live and standing dead) including belowground biomass in coarse roots, understory vegetation, down dead wood, litter, and soil.

Any emissions from project-related activities (e.g., equipment used for clearing or planting) should also be included in the GHG accounting boundary. The methodology and tool do not currently include GHG accounting for equipment use in the reforestation/afforestation operation, but could be modified to include that if warranted and data become available. These emissions should be factored into any reduction claims.

Temporal Boundary. Terrestrial carbon sequestration is unlike other GHG mitigation activities because of the time dynamics introduced. Carbon is sequestered at different rates over the life of a forest stand, with little accumulation in the first few years, rapid accumulation after that, and a slowing of carbon sequestration in forests when they reach a certain age. This steady state condition varies by species and region, but ranges from several decades to more than 100 years. The methodology outlined in this paper is based on a performance standard set by assessing similar practices in a relevant geographic area (see below for more details). In other sectors, this typically represents the emissions rate of a high performing technology used in the production process of interest (e.g., CO_2 emitted per kilowatt hour of electricity generation), a technology standard or a practice standard. For most project types, this standard may be seen as having a limited period of relevance, as the best practices eventually become standard practices. But this is not as relevant for reforestation/afforestation. Reforestation/afforestation involves moving from one economic activity (e.g., agriculture) to another (e.g., forestry) so there is really no natural time for the rest of the sector to "catch up". Therefore, in principle the performance standard should continue as long as the project is being monitored. We select a time period of 20 years here, which roughly matches the length of the shortest timber rotations we might expect to see in a forestry operation. The time period can easily be extended and baselines modified as needed.

Permanence. Much of the carbon stored in forest ecosystems is in a volatile form, with corresponding risks of release through either deliberate action (harvesting) or unplanned disturbances such as wildfire or pest outbreaks. This has raised issues about the "permanence" or potential "reversibility" of carbon sequestered in forests. Carbon accumulated from reforestation/afforestation must be monitored over an extended period of time to properly account for variable growth rates and reversal risk. In principle, this could be into perpetuity. But in practice, project contracts are likely to be for a finite life. If so, then some provision should be made at the end of the contract to properly account for the possibility that the stored carbon will be released after the project ends. Requirements for addressing permanence will be established as a component of the Climate Leaders offsets program design.

Leakage. Leakage is an increase in greenhouse gas emissions or decrease in sequestration caused by the project but not accounted for within the project boundary. The underlying concept is that a particular project can cause emissions to occur outside of the physical boundary that fully or partially negate the benefits of the project. For example, if the boundary is set as the parcel on land on which planting is to occur, and the land owner opts to deforest another parcel of his or her property in order to make up for the lost cropland or pasture converted for the offset project, this would qualify as leakage that negates all or some of the carbon benefits of the offset project. This type of internal leakage can be addressed by ensuring the project boundary encompasses all of the landowner's holdings.

Although there are other forms of leakage, for this performance standard, leakage is limited to activity shifting – the displacement of GHG activities outside of the project boundary. If it is determined that significant emissions that are reasonably attributable to the project occur outside the project boundary, these emissions must be quantified and included in the calculation of reductions; however, no specific quantification methodology is required. All associated activities determined to contribute to leakage should be monitored.

Regulatory Eligibility

The performance standard subjects greenhouse gas offset projects to a regulatory "screen" to ensure that the emission reductions or increased sequestration achieved would not have occurred in the absence of the project due to federal, state or local regulations. In order to be eligible as a GHG offset project, GHG emissions must be reduced below or carbon sequestration increased above the level effectively required by any existing federal, state, or local policies, guidance, or regulations. This may also apply to consent decrees, other legal agreements, or federal and state programs that compensate voluntary action.

Federal Regulations. There are no broad federal policies, guidance or regulations requiring afforestation or reforestation of non-forested private lands. One narrow provision that could apply, however, is the requirement to address surface effects of underground mining:

> Title 30 (Mineral Lands and Mining), Chapter 25 (Surface Mining Control and Reclamation), Subchapter 5 (Control of the environmental impacts of surface coal mining), Section 1266b.6 [requires]
> (6) establish on regraded areas and all other lands affected, a diverse and permanent vegetative cover capable of self-regeneration and plant succession and at least equal in extent of cover to the natural vegetation of the area;

Therefore, a reforestation/afforestation project proposed for surface areas of strip or underground coal-mining operations may be considered a form of regulatory compliance if this statute applies and might not be considered "additional" from a GHG offset perspective.

State and Local Regulations*.* Although some states require reforestation of stands after timber harvest, essentially no states or localities specifically require that non-forested private lands be converted to forest[3]. As land use statutes are numerous, location-specific, and ever-changing, the prospective project developer should consult state and local land use laws to determine whether any such mandates for reforestation/afforestation activities exist in the relevant geographic area of the project.

Voluntary Landowner Compensation Programs*.* There are numerous federal and state programs that compensate landowners for establishing forests on marginal agricultural lands or other environmentally sensitive areas. One prominent federal program is the Conservation Reserve Program (CRP). The CRP (http://www.nrcs.usda.gov/programs/crp/) pays farmers to establish vegetative cover, including trees, on highly erodible or other environmentally sensitive land.

In addition to the federal programs, state and local programs may apply, as do compensation agreements with private conservation organizations and other non-governmental organizations. Together these forms of compensation for establishing forests for purposes other than GHG mitigation raises the question of whether such projects should also be eligible for payments in a GHG offset program. This is based on concerns that the GHG benefits of such a project would not be additional to what would otherwise occur in the absence of the GHG program, presuming that the afforestation would have occurred anyway as a result of the other programs.

Determining Additionality – Applying the Performance Threshold

This section describes the process by which a carbon sequestration performance threshold is established for a reforestation/afforestation project. The purpose of a performance threshold is to determine the additionality of a project. A project's GHG

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[3] One possible exception is in the state of Maryland, wherein all parcels of land above 40,000 square feet are required to have a certain percentage of vegetative cover (the percentage depends on the parcel size).

benefits are additional to the extent that sequestration exceeds what would have occurred under a business as usual (no-project) scenario.

Additionality Determination. The additionality determination represents a level of performance that, with respect to emission reductions or removals, or technologies or practices, is significantly better than average compared with similar recently undertaken practices or activities in a relevant geographic area. Any project that meets or exceeds the performance threshold is considered "additional" or beyond that which would be expected under a "business-as-usual" scenario.

The type of performance threshold used for eligible reforestation/afforestation projects is practice-based. The practice-based performance threshold represents a level of "performance" that is beyond that expected for the management of cropland or pasture, specifically regarding typical practices to convert such lands to forest. The performance threshold reflects the actions of other relevant individuals who, similar to the potential project owner, hold non-forest land that could be converted to forest or other uses. The performance standard is, therefore, based on the range of current afforestation and reforestation practices on nonfederal cropland and pasture. In most cases in the U.S., the relevant entities for comparison are private farmers who currently use the land for agriculture.

The principal task of setting this practice-based performance threshold for reforestation/afforestation projects is determination of the probability of conversion of cropland or pasture to forest under business-as-usual (BAU) conditions for the appropriate geographic area. This may be accomplished by running the RAPCOE tool which automates the calculation of the estimated rate of conversion to forest. This is a simple calculation of the mean land use transition rate for the region of interest, one that can also be easily calculated by any party with access to NRI data (see Appendix A). A minority of the agricultural land areas available for afforestation or reforestation are converted to forest in the United States. Therefore, afforestation and reforestation activities for most parts of the U.S. are considered "beyond common practice" and, therefore, additional. In the United States, the highest average "business as usual" rate (15-year mean value) for conversion of cropland to forest is 2.31%, in the Eastern Gulf Coast Flatwoods. For conversion of pasture to forest, the highest 15-year rate is 2.37%, in the Sierra Nevada Basin. The lower bound for conversion of either pasture or cropland to forest is 0%.

As mentioned earlier, the RAPCOE tool was developed in order to automate the methodology. RAPCOE is used both for application of the performance threshold for determining additionality, described above, as well as baseline setting and estimation of the gross and net offset potential of the project, described in the following section.

Quantifying Emission Removals

Quantifying emission removals from reforestation/afforestation projects encompasses four steps: two are pre-project implementation (selecting the baseline and estimating project emission reductions and/or removals) and two are post-project implementation (monitoring and calculating actual project reductions and/or removals).

Selecting and Setting a Removal Baseline. A background rate of land use change from agriculture to alternative uses should be considered in estimating the baseline rate of carbon accumulation on the landscape without the afforestation or reforestation project. These rates of land use change, however, vary spatially, and so determination of a project's sequestration relative to a background rate of land use change must be done on a regional or sub-regional scale.

For this performance standard an eco-region level of spatial aggregation is used. In principle, the carbon profile of land changes when agricultural land is converted to other uses. The change, however, will be very site-specific. These changes tend to produce a higher amount of carbon stored on site as perennial crops under conventional cultivation are replaced, for example, with grasses or trees.

There are 3 main steps to establishing the baseline:

1. Determine the probability of each land-use transition under business-as-usual (BAU) for the geographic location
2. Estimate the carbon sequestration consequences of each land use transition.
3. Estimate the total project baseline by summing across the products of each transition and the associated carbon stock changes.

If the land were not converted to forest via the project, then it could experience any one of the following land use transitions under business-as-usual conditions (as referred to in steps 1-3 above):

Potential Land Use Transitions

Starting in cropland	Starting in pasture
• remaining in **cropland**	• converted to **cropland**
• converted to **pasture**	• remaining in **pasture**
• converted to **forest**	• converted to **forest**
• converted to **developed use**	• converted to **developed use**

Further details on steps 1 – 3 are provided in Appendix B.

Both the land use transitions and carbon consequences are time-dependent, therefore, the baseline estimation must explicitly account for time dynamics.

Estimating Project Emission Removals. At the pre-implementation stage, quantifying the carbon sequestration effects of the reforestation/afforestation activity is a predictive exercise rather than an observational one. Therefore, some sort of model or secondary data source is necessary to generate the prediction. The recommended default approach is to use the FORCARB2 stand-level and wood product forest carbon tables, as used in the RAPCOE tool. These have been developed by scientists at the USDA Forest Service and are part of the 1605(b) reporting guidance for forestry projects[4]. The project developer can use alternate models or datasets if found to be more suitable for their particular project. This may, however, result in more thorough review of the project description and reduction claims.

To estimate project removals, gross sequestration from the project must be estimated, and then adjusted to account for both the baseline sequestration for the project area and any estimated leakage from the proposed project. The general formula for this calculation is:

Project Net Emission Offset = [Gross Carbon Sequestration from Afforestation - GHG Baseline]*[1 – Leakage%]

Monitoring

In this section, two specific recommendations are presented for post-project monitoring: (1) modeling and (2) direct field measurement. A more detailed background paper on monitoring will be provided on the Climate Leaders website. Monitoring requirements will be more thoroughly developed as a part of overall offsets program design.

Models: A variety of models are available for simulating carbon sequestration for different forest conditions and management activities. Models useful for estimating carbon sequestration may be based on traditional empirical timber production models modified to predict carbon stocks. The use of well-established, locally parameterized growth and yield type models such as those commonly used by the forest industry represent an acceptable methodology and can produce quantifiable uncertainty. These models are relatively low cost because generally the industry has such models on hand to predict the production of their product. Furthermore, repeated measurements to the extent required for the direct field measurement approach would not be needed as

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[4] Smith, James E.; Heath, Linda S.; Skog, Kenneth E.; Birdsey, Richard A. 2006. Methods for Calculating Forest Ecosystem and Harvested Carbon with Standard Estimates for Forest Types of the United States. Forest Service, Northeastern Research Station, General Technical Report NE-343. 216 p. Downloadable at http://www.fs.fed.us/ne/durham/4104/papers/ne_gtr343.pdf

these models tend to be well tested over different age classes and site indices already. Periodic field measurements for validation would, however, be necessary

Implementing a modeling methodology involves the following steps:

1. Select a model that is applicable to the particular project (estimates carbon stocks for the particular forest type and species, as well as the selected pools of interest). The model should also be based on peer-reviewed concepts.
2. Determine the area of land to be included in the estimate, and characterize that area in a way that is compatible with estimates from the model.
3. Parameterize the selected model for the specific conditions of the project area to which the model is applied.
4. Implement periodic validation of model estimates of carbon stocks with field data and sensitivity analyses.

Direct field measurements: This methodology involves developing and implementing a field sampling and estimation approach appropriate and efficient for the project area being measured. Implementing the direct field measurement methodology involves the following steps:

1. Delineate of the area into strata to be sampled;
2. Determine the type and number of sample plots required and an efficient sample plot layout;
3. Decide which pools and corresponding variables to measure[5];
4. Collect and compile the data;
5. Convert the raw data into carbon stock estimates and determine total error
6. Perform quality assurance and quality control over the monitoring operation.

For this methodology, the desired precision and the variability of carbon stocks expected in the project should be considered. If the variability (measured by the coefficient of variation) is low (20-30%) as might be expected on productive sites, then the number of plots needed to target a precision level of 10% with a 95% confidence interval could be low—10-25 plots (regardless of size of project area). Thus, for a site that was less productive or more heterogeneous, a lower confidence interval could be set to reduce costs—e.g., with a CV of 30% 32 plots would be needed for a 95% CI with a precision level of 10% and only 23 plots for a 90% CI with precision of 10%. The carbon stocks in the other components could be derived from the look-up tables in a manner similar to that described for models. Unlike the

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[5] At this time, it would not be required to collect field measurements of the soil carbon pool.

modeling monitoring option, there would be repeated measurements over time.

Calculating Actual Project Removals. Quantifying project carbon removals occurs after the project has been implemented and monitored. To quantify project removals, the project developer must take the gross sequestration from the project, with calculations based on resulting data from application of one of the monitoring options described above, and adjust this to account for the baseline sequestration for the project area and any estimated leakage from the proposed project. The general formula for this calculation is the same equation applied to estimate the net offset potential at the pre-project stage, with the exception that, actual monitored project data is now used, rather than the pre-project estimates.

Appendix I. Datasets for Setting the Performance Standard (Performance Threshold and Baseline)

I. *Historical land use change data*

The baseline land use projections are based on patterns observed in historical land use data. The historical data for conversion to forest are also applied to determine additionality. The objective of this methodology is to be applicable across the continental U.S., so the focus is on data sets that have national scale coverage. Two candidate data sets were identified for this purpose.

> **National Resources Inventory (NRI)**. The NRI is a combination of remotely sensed and field-sampled data collected by USDA's Natural Resources Conservation Service (NRCS). The NRI provides nationwide coverage, and on a recurring basis, collects data on, among other things, land use for 800,000 sample points nationwide in the U.S. NRI data can be employed to estimate the rate of land use changes among different land use types (see http://www.nrcs.usda.gov/technical/NRI/ for more detailed information).
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> **National Land Cover Dataset (NLCD)**. The NLCD is a land cover classification scheme, available for 1992 and 2001, that has been applied over the conterminous United States. It is based primarily on Landsat Thematic Mapper imagery. The NLCD contains 21 categories of land cover information, which have been aggregated into the six IPCC land-use categories, and the data is available at a spatial resolution of 30 meters.

Because of the infrequency of the NLCD data, and the higher uncertainty relative to the NRI, we recommend using the NRI as the default data source and, therefore, have used this data in developing this methodology and the RAPCOE tool. As indicated above, however, NRI data availability is limited in post-1997 years. If project developers have regional land use data of better quality or frequency, they may wish to consider using that data, subject to the approval of the program.

Considerations for Selecting Data

1. Spatial Resolution

Region-specific afforestation and reforestation estimates, rather than national, are recommended due to the spatial variability in land use change rates and carbon stock potentials of different vegetation classes. The appropriate question, then, is which level of spatial resolution is the most appropriate for defining regions for estimation of land use change rates.

For this methodology, an eco-region level of spatial resolution has been selected.

Scientists and government agencies have developed land classification systems that aggregate land into ecologically similar clusters, or eco-regions. One example is the NRCS' Major Land Resource Area (MLRA) (soils.usda.gov/survey/geography/mlra/index.html) classification system. An advantage of the MLRA system is that NRI data carry the MLRA data category in each record and can thereby be clustered accordingly. There are 204 MLRA regions identified in the 1997 NRI data.

The RAPCOE tool aggregates up to the MLRA eco-region level. This is necessary as NRI data are not collected with the objective of county-level precision. It is suggested that data not be used for analysis below a multi-county level. RAPCOE still allows the user to choose a particular county, as most users would not be readily familiar with the MLRA that the county of interest falls in, however, the county data actually reflects the value for the MLRA in which the county is located.

2. Temporal Range

The potential temporal range for the land use data used to determine the baseline land use transition rates depends on the choice of land cover datasets. As indicated above, the NRI followed a 5-year sampling plan from 1982 through 1997, with data for the 800,000 sample plots reported at 5-year intervals within this time period (1982, 1987, 1992, 1997). Despite the lack of recent updating, NRI is still the most comprehensive land use data source and is recommended as the default data source so the data's temporal range is 1982-1997. If updated NRI data or NLCD data do not become available over time, however, it may be necessary to modify this methodology or to allow project developers to obtain there own data or provide other justification for determining baseline rates of land use change. The accompanying software tool allows this flexibility.

II. ***Forest ecosystem carbon data***

The FORCARB2 carbon yield tables[6] provide estimates of *in situ* carbon storage levels on a per-acre and per-hectare basis, starting in Year 5 after conversion, and reporting at 5 or 10-year time intervals (depending on region) for the following forest carbon pools:

- Trees (live and standing dead)
- Understory vegetation
- Down dead wood

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[6] FORCARB2 carbon yield tables for forest ecosystem pools and wood products were developed by the USDA Forest Service as part of the 1605(b) reporting guidance for forestry projects. The tables are based on outputs of the latest version of the USDA Forest Service's FORest CARBon model (FORCARB2), which estimates forest carbon stocks based on field survey data from the Forest Service's Forest Inventory and Analysis (FIA) program.

- Forest floor litter
- Soils

The tables include data for afforestation, which captures reforestation as defined in this methodology, and can be found in Appendix B (p.110) of the reporting guidelines found at:

http://www.usda.gov/oce/global_change/Forestryappendix.pdf

The standardized methodology described in this document and the related RAPCOE tool are both linked to the use of these tables.

Appendix II. Detailed Steps for Determining the Baseline

I. Estimate rate of land use conversions using selected historical data

The land use change rates for the four possible transitions that either cropland or pasture can undergo in each region can be calculated as follows:

$$Z^{ij}rt = L^{ij}{}_{rt,t+1} / L^{j}{}_{rt} \qquad [1]$$

Where $L^{ij}{}_{rt,t+1}$ is total land area that transitions from land use i to land use j in region r between time period t and t+1 and $L^{i}{}_{rt}$ is total land area in land use i in region r in time period t. Following the discussion above, i = j = 4. All land use transition rates for the region sum to 1.

$$\Sigma_{j=1} Z^{ij}rt = 1.0 \qquad [2]$$

Determining the baseline rate of land-use change for a given region requires estimating the land-weighted proportion of NRI sample points in that region that started in use i and transitioned to use j over a given time horizon. Note j includes i, thereby capturing land remaining in its original use as well as land transitioning to other uses. One can use all 15 years from 1982-1997 as the beginning and end points, or just the last 5 years. The RAPCOE tool uses the 15-year mean for the baseline land-use conversion rate.

In addition to establishment of the baseline, the 15-year means for land-use conversion rates from cropland to forest and pasture to forest also allow determination of additionality.

Running the RAPCOE tool demonstrates that, for most regions in the United States, most land originating in cropland or pastureland remains in that use with little transition between cropland and pasture and low levels of both reforestation/afforestation as well as conversion to developed use.

Other methods for estimating the baseline land use conversion rates

Alternative approaches to calculate the sample average can be employed to estimate land use change rates at the regional level. For example, Murray and Sommer (2004) use statistical discrete choice regression analysis to estimate county-specific afforestation rates as a function of location and physiographic characteristics for a watershed-sized region in the lower Mississippi alluvial valley[7]. Several studies have

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[7] Murray, BC and AJ Sommer. 2004. "Setting Baselines for GHG Mitigation Projects in Agriculture, Land Use Change and Forestry: A Comparison of Bottom-Up and Top-Down Approaches." Paper prepared for US EPA Climate Change Division. Email brian.murray@duke.edu to obtain.

used econometric model to estimate land use change by major category at the regional[8] and national levels[9]. While these more sophisticated approaches have their advantages, the land use change projections may not be applicable to all regions within the U.S. and are not readily available to the public for use in the project baseline-setting context. Moreover, the method is not quite as transparent as the sample mean approach discussed above. Therefore, the sample mean approach is recommended as the default approach to follow and has been used in the accompanying RAPCOE tool. Individual users are, however, given the option, if they have access to data or models to perform the estimations, to use these and enter their own historical land use conversion rates in RAPCOE.

II. Estimate carbon effects over time for each baseline land use transition trajectory

Each potential land use transition identified above has a unique carbon sequestration potential over time. The assumptions and datasets for each land use transition are summarized in Table 1 and described for each transition below.

Cropland remaining in cropland and pasture remaining in pasture

Cropland and pasture projected to remain in their current use under BAU conditions are assumed to be in a steady state condition with no expected gains or losses in carbon over time.

Cropland converted to pasture and pasture converted to cropland

Cropland that is projected to convert to pasture under BAU conditions would generally accumulate carbon in the upper soil layer as soil cultivation (tillage) ends and permanent grass cover takes hold. Soil carbon storage is projected to increase at an even rate over a 20 year time period until the pasture soil carbon steady state is reached.

When pasture is converted to cropland, soil carbon is lost as the permanent grassland is cultivated for use in crop production. So BAU conversion of pasture to cropland can be viewed as a baseline source of emissions. It is assumed that all of the incremental soil C content in pasture (relative to cropland) is lost within 5 years after pasture is converted to cropland. Pasture projected to convert to cropland would generally be marked by a carbon loss in the soil due to cultivation.

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[8] Hardie, I., P. Parks, P. Gottlieb, and D. Wear. 2000. Responsiveness of rural and urban land uses to land rent determinants in the south. *Land Economics* **76**(4):659-673.

[9] Lubowski, R.N., Plantinga, A.J., and R.N. Stavins. 2006. Land-Use Change and Carbon Sinks: Econometric Estimation of the Carbon Sequestration Supply Function. *Journal of Environmental Economics and Management* 51(2):135-52.

Reforestation/Afforestation: Cropland or pasture converted to forest

The rate of carbon accumulation for baseline reforestation/afforestation activity is based on the FORCARB2 model of Smith et al (2006), as described earlier. There is no distinction made between a reforestation/afforestation that originates on cropland versus reforestation/afforestation on pasture in terms of the amount of carbon gained over time.

Cropland or pasture to developed use

In principle, the carbon profile of land changes when agricultural land is converted to developed use. However, the change will be very site-specific. For instance, cropland converted to a housing development results in a different mix of vegetation. By and large, these changes would tend to produce a higher amount of carbon stored on site as perennial crops under conventional cultivation are replaced with grasses, trees, and ornamental vegetation that is more permanent.

We follow an assumption used in the Forest and Agricultural Sector Optimization Model – Greenhouse Gases (FASOMGHG model)[10] that stipulates a weighted average carbon content for developed lands of 40% pasture and 60% forest: carbon on developed land is assumed to be a weighted share of carbon found in pasture (40%) and forest (60%). Thus, if land starting in cropland is expected to convert to developed use, we multiply the cropland to pasture carbon accumulation rate by 0.4 and the cropland to forest carbon accumulation rate by 0.6 to get the weighted accumulation rate. For pasture converting to developed use, we multiply the pasture to forest accumulation rate by 0.6 and set that as the total accumulation rate, since the pasture part of the landscape remains unchanged.

Table 1. Carbon Effects for each Land Use Transition: Summary			
Land Use Transition	Carbon effects	Data/model source	Temporal dynamics
Starting in			

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[10] McCarl, Bruce A. 2006. Personal communication of data from the Forest and Agricultural Sector Optimization Model – Greenhouse Gases (FASOMGHG). Model under development and documentation forthcoming.

cropland			
• remaining in cropland	No net carbon change assumed	NA	NA
• converted to pasture	Carbon gained through accumulation in soil	FASOMGHG model data (McCarl, 2006)	Carbon accumulates over 20-year time period after conversion
• converted to forest (afforestation)	Carbon gained through accumulation in soil, trees, other vegetation and woody debris	FORCARB2 Model (Smith et al 2006)	Carbon accumulates at variable rate over extended period after forest establishment (up to 100 years +)
• converted to developed use	Carbon on developed land assumed to be weighted share of carbon found in pasture (40%) and forest (60%)	FASOMGHG model data (McCarl, 2006)	Carbon accumulates over 20-year time period after conversion
Starting in Pasture			
• converted to cropland	Carbon lost through cultivation of soil	FASOMGHG model data (McCarl, 2006)	All carbon is lost within 5-year period
• remaining in pasture	No net carbon change assumed	NA	NA
• converted to forest (afforestation)	Carbon gained through accumulation in soil, trees, other vegetation and woody debris	FORCARB2 Model (Smith et al 2006)	Carbon accumulates at variable rate over extended period after forest establishment (up to 100 years +)
• converted to developed use	Carbon on developed land assumed to be	FASOMGHG model data (McCarl, 2006)	Carbon accumulates over 20-year time

	weighted share of carbon found in pasture (40%) and forest (60%)		period after conversion

III. Estimate baseline from land use transition and GHG data

This step takes the land use change rate projections from Step I and combines these with carbon effects for each possible transition in Step II to estimate the project carbon baseline.

The amount of carbon that accumulates during the baseline projection period can be calculated using a form of cohort group accounting. The estimated annual land use change rates (Step I) provide empirical evidence on the extent to which the agricultural land targeted for the project would change use under BAU conditions. Under BAU, presumably, this happens steadily over time rather than all at once. Therefore, the baseline calculation must properly handle the time dynamic this implies.

For the portion of the project area projected to transition under BAU in any given year, its carbon would begin to accumulate in that year and in all future years throughout the baseline projection. This is calculated for all predicted land use transitions for the baseline projection period. At the end of the baseline projection period, the estimated carbon that would have been expected in the project area can be estimated by summing the accumulated carbon for all potential land use transitions.

EPA United States
Environmental Protection
Agency

Office of Air and Radiation (6202J)

EPA400-S-08-007

August 2008

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