Appendix H: Illustrative Biogenic Landscape Attributes Using a Retrospective Reference Point Baseline

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1. Introduction

This appendix describes potential methods for calculating regional default values for the landscape biogenic attributes (*GROW*, *AVOIDEMIT*, and *SITETNC*) associated with sample feedstocks and regions using a retrospective reference point baseline. The calculations presented in this appendix are meant for illustration only, as proof-of-concept exercises, to show how these values might be calculated. They are not meant as final values for use in a particular stationary source program for any particular feedstock.

This appendix uses the retrospective reference point baseline approach to produce illustrative equation term values for three of the landscape biogenic attribute terms (*GROW*, *AVOIDEMIT*, and *SITETNC*) from the biogenic assessment factor equation in the main report (Part 2):

$$\boldsymbol{NBE} = (\boldsymbol{PGE})(\boldsymbol{GROW} + \boldsymbol{AVOIDEMIT} + \boldsymbol{SITETNC} + \boldsymbol{LEAK})(\boldsymbol{L})(\boldsymbol{P}) \qquad \textbf{(EQ. H.1)}$$

Although leakage (represented by the *LEAK* term) is also a landscape biogenic attribute, this term is not calculated in the proof-of-concept term calculations presented here. Appendix E provides further discussion on leakage.

The framework defines the biogenic landscape attribute equation terms addressed in this appendix as:

- *GROW*: *GROW* represents the ratio of net feedstock growth on the biogenic feedstock production landscape relative to landscape biogenic carbon removals. This term only includes biogenic carbon within the feedstock carbon pool.

- *AVOIDEMIT*: *AVOIDEMIT* represents the ratio of avoided biogenic emissions that would have occurred on the feedstock production landscape without biogenic feedstock removal (such as removal of corn stover and logging residues) to landscape biogenic carbon removals.
- *SITETNC*: *SITETNC* represents the ratio of the estimated total net change in non-feedstock carbon pools on the feedstock production site due to land use management or land use management changes associated with feedstock production to landscape biogenic carbon removals.

Illustrative equation term values are generated using the retrospective reference point baseline approach in the context of three specific feedstock/region combinations:

- Roundwood in the Southeast (SE);
- Logging Residues in the Pacific Northwest (PNW); and
- Corn Stover in the Corn Belt (CB).

2. Illustrative Method for Developing Regional Default Values for Biogenic Attributes: Southeast Roundwood

This section explains the method by which regional default values for *GROW*, *AVOIDEMIT*, and *SITETNC* were developed for the illustrative application to Southeast Roundwood. In this context, roundwood is defined as the portion of tree biomass that would be defined as “merchantable” according to existing forest inventory definitions. This includes trees of commercial species, with good form (e.g., not hollow or “cull”), large enough to be harvested, and includes the main bole or stem but not branches or tops.

2.1. *GROW*

In general, the *GROW* term represents net feedstock growth on the biogenic feedstock production landscape. Estimating a value for *GROW* at a regional level using the retrospective reference point baseline could use an assessment of recent forest growth and harvest in the feedstock’s source region. Therefore, in this specific baseline context, *GROW* can be represented as the ratio of removals less growth over removals of roundwood in the source region over the most recent forest inventory cycle:

$$\boldsymbol{GROW_{Roundwood} = \frac{REMOVALS - GROWTH}{REMOVALS}} \qquad \textbf{(EQ. H.2)}$$

For this illustrative retrospective reference point baseline approach application, computation of the *GROW* term ($(R–G)/R$) is based on forest inventory data collected by USDA Forest Service in the Forest Inventory and Analysis (FIA) program. The FIA data representing the most recently completed inventory for a region are used. The FIA program defines several types of growth and removals values. Growth is measured in FIA by comparing tree measurements from specific plots in the current inventory cycle with measurements from previous cycles, enabling a tree-by-tree estimate within remeasured plots. In addition, as plots that were previously not forested become forested, any tree volume on these newly forested plots represents growth, or additions to the forest stocks. FIA defines “gross growth” as the sum of growth across all trees on all plots. FIA defines "net growth" as the gross growth minus the volume of trees that die during a remeasurement period, termed mortality:

$$\textbf{\textit{Net Growth = Gross Growth – Mortality}} \qquad \textbf{(EQ. H.3)}$$

Standard FIA reports include net growth and mortality, but not gross growth. As this framework application is meant to assess the feedstock carbon (C) stock on the landscape in the *GROW* term, and thus includes standing dead trees in the estimate of *GROW*. Thus the mortality is added back to the reported net growth to obtain an estimate of gross growth for use in the calculation of *GROW*.

Removals are estimated by FIA when remeasured plots reveal the absence of trees that were measured in a prior inventory cycle. Removals may include wood biomass removed from forests during normal harvest cycles and during conversion of forest to some other land use. Both components are important in evaluating the balance of growth and removals in a region to assess the drivers of biomass removal and fluxes between terrestrial and atmospheric carbon pools.

2.1.1. Data

The FIA program data is utilized as it represents forest inventory data across all ownerships and regions across most of the United States. The FIA program measures forest plots in different states annually, such that a portion of field plots (termed a "panel") are measured in each state each year. For example, in the east (easternmost five regions), there are five panels so that it takes 5 years for all plots in a state to be remeasured. The length of time it takes to remeasure all panels in a state is called the inventory cycle. Inventory cycles in the west are longer than in the east: up to 10 or 15 years may be required to measure all panels in a western state's inventory.[1] All FIA data (except precise locations of field plots and specifics about ownership of each plot) are available to the public via the FIA web site: http://fia.fs.fed.us. For this example, data were downloaded in Access database format for each state in the Southeast. This analysis used data from the most recently completed inventory for each state in the region.

2.1.2. Forested Land Designation Used

In some policy-specific framework applications, it may be appropriate to use a specific forested land designation, such as all forestland, all timberland, or working forest. In a situation where a "working forest" designation is appropriate, FIA data can be screened to develop estimates only for the forest resource in each region that is defined as the "working forest." The approach and definitions of working forest used in this application, as well the implications of choosing alternate proof-of-concept, land-based designations—e.g., all forest lands, all timberlands, private forest

[1] FIA data are now collected in a nationally consistent manner, although the program is still in transition to this format and many western states do not yet have sufficient data collected under this program to enable computation of growth and removals. For example, remeasured data are currently not available for many states in the west (the Intermountain, Pacific Northwest, and Pacific Southwest regions). Specifically, California, Oregon, and Washington started collecting the nationally consistent data later than other states, and USDA Forest Service will only release data once a sufficient number of panels have been measured to allow for reliable estimates.

lands, public forest lands, working timberlands, private working timberlands—are described below.

2.1.2.1. Defining the Working Forest

The concept of a working forest recognizes that portions of the forest resource within a region are unlikely to be used for feedstock production (Buchholz et al., 2011). Examples of such forest resource areas include protected forest areas, areas not conducive to harvest due to physical conditions (e.g., inoperable soils or steep slopes), areas subject to regulatory restrictions on harvest (e.g., elevation limits in the Northeast), and areas where harvest is not economically feasible (e.g., large distance to transportation networks).

Because harvest of forest resources for biogenic feedstocks is unlikely for certain forest conditions, those areas are excluded from consideration in the *GROW* term in this specific illustrative application. If the growth/removals balance used to calculate values for the *GROW* term were applied to the entire forest landscape within a region, and not to the working forest only, then growth (and related CO_2 capture) in areas protected from harvest or not viable for harvest would be included along with removals (and related CO_2 emissions) from the working forest. This could mask the actual growth/removals dynamics related to the use of forest biogenic feedstocks, and the related carbon cycle effects on the landscape of such use. For application of this framework at the regional scale, the goal is to identify the biogenic carbon cycle impacts related to stationary sources using biogenic feedstocks. Clearly defining the working forest, i.e., that portion of the landscape from which biogenic feedstocks are most likely produced, is an important first step.

There is an active debate about exactly what constitutes the working forest land base (i.e., Alig et al., 2002). Some fraction of the land base is "reserved" by legal limits on logging, and there is clearly a significant fraction of the remaining forest land that is not available for harvest because of a wide range of biological, physical, legal, economic, and social concerns (Buchholz et al., 2010; Butler, 2008). These limits on the availability of working forest land are difficult to quantify and may vary over time. For example, the increasing "parcelization" of forest land (i.e., subdivision into smaller ownerships) is generally assumed to reduce the land available for harvest because harvest operations are impractical on very small landholdings.

To stratify by working forest for this analysis, the first step is the selection of criteria (parameters) that can be used to define the working and non-working forest, and to set thresholds for those criteria. For example, if it is unlikely that harvest occurs on slopes exceeding 50%, then a slope threshold of less than 50% can be applied to a "slope" parameter to form a part of the working forest definition.

For the illustrative calculations for the *GROW* term below, working forest was defined using a set of physiographic, location, and other factors determined through the plot characteristics in the FIA dataset from the USDA Forest Service. For proof-of-concept, these national criteria nationwide are applied, as working forest can be defined using criteria that may differ by state and/or region,[2] using limits set by local expertise, or using analysis of FIA plot characteristics that have had harvests recorded.

To obtain estimates of forest biomass in the working forest, the first step is to "screen" or filter FIA plots to determine which plots fall within definitions of the working forest. Then, FIA data are summarized for the screened subset of all forest plots. In this example, working forest is defined by five criteria, following Butler et al. (2010):

(1) Access: Areas greater than a mile from improved roads are considered too costly to harvest;
(2) Physiographic condition: Hydric soils are indicative of wetland conditions and are often not suitable for operation of harvesting equipment, so sites classified as hydric physiographic conditions are excluded from the working forest;
(3) Productivity: Sites with very low forest productivity are usually not suitable for biomass production and are thus not typically used for feedstock production; these are excluded from the working forest;
(4) Harvest restrictions: Sites where timber harvest is legally restricted (for example, some national parks and wildlife refuges) are excluded from the working forest; and
(5) Steep slopes: Timber harvest is typically constrained on steep slopes. Thus, sites with slope greater than 50% are excluded from the working forest.

The working forest was defined here by screening out FIA *conditions* (portions of plots) not meeting these specified criteria for working forest. Plots that do not match the definition of working forest were removed from the analysis dataset for each year. The remainder of the plots represents the working forest, and these were used to develop the carbon stock estimates for calculating values for the *GROW* term).

Table H-1 shows the proportions of overall forest area and aboveground biomass that would be included as working forest for each region, based on the five screening criteria described above.

Table H-1. Proportions of Overall Forest Area and Biomass that Would Be Included as "Working Forest" for the Southeast and South Central RPA Regions (2010 FIA Data Using FIA Database (FIADB) (version 5; Woudenberg et al., 2010) Query Tools to Screen for Working Forest).

Region	Percent of Forest Area	Percent of Biomass
Southeast	82.1%	80.4%
South Central	62.4%	77.7%

FIA reports focus on specific variables with important meanings. First, they report on "forestland" and "timberland." Timberland is a subset of forestland that is not specifically reserved from timber production and meets a minimum productivity threshold. For maximum flexibility in application, the analysis herein is based on reports using "forestland." Second, volumes reported may be for "all

[2] For example, some states have harvesting restrictions that apply to certain elevations, slopes, or proximity to water that may not apply in other states.

live" trees or "growing stock" trees. Growing stock trees are limited to commercial species meeting specified standards of size, quality, and vigor. Because these default criteria are oriented towards traditional forest products and not biomass harvest, the analysis herein expanded the analysis to use "all live" tree reports. To include standing dead trees in the estimates, mortality is added to net growth to obtain gross growth; if standard net growth estimates had been used, standing dead trees would have been excluded from the analysis.

Standard FIA reports for growth, mortality, and removals use units of cubic feet. Conversion to metric tons of CO_2e involves multiplying by a constant conversion factor if metric tons CO_2e are the units being used. However, if landscape attribute terms are presented as unitless ratios in a specific application of the framework, it is not necessary to convert to metric tons CO_2e (and results can be left in the original units of cubic feet).

2.1.3. Results

The methodology used for the analyses here began with identification of the time period for analysis, which was the inventory cycle ending in 2010. Next, the extent of the working forest was identified. Then, using the FIA Database (FIADB) (version 5; Woudenberg et al., 2010) query tools, the following queries were run for working forests in each state for each year:

- "Net growth of all live on forestland: cu. ft/year;"
- "Mortality of all live on forestland: cu. ft/year;" and
- "Removals of all live on forestland: cu. ft/year."

The annual net growth and mortality estimates were added to compute gross growth.[3] Estimates for each state in a region are summed. Then, *GROW* is computed as the ratio of removals less growth over removals.

Table H-2. *GROW* Term for the Southeast Roundwood Example (2010 FIA Data, Based on Working Forests).

Region	Gross Growth (million cu. ft/yr)	Removals (million cu. ft/yr)	*GROW*
Southeast	7,603.5	4,379.7	−0.74

[3] Note that removals from plots that were converted from working forest at their previous measurement to non-forest as of the most recent measurement were not included in this analysis. This occurred because the screening for working forest is based on the area of the working forest at the most recent remeasurement. For example, consider a plot that is part of the working forest at the prior inventory measurement. The plot is then harvested as part of a conversion to a non-forest type (e.g., development). Because the plot is not part of the working forest at the most recent remeasurement, these removals are not included in the standard reports that are based on working forest plots. Thus, a more complex approach involving selection of plots that have been converted from working forest to something else, and then removals estimation for these plots, is needed. The removals from these converted plots should be added to the removals in the denominator of the *GROW* term. Because the number of plots in this category is so small, and the value of G/R is so comparatively large, this omission is unlikely to change the *GROW* term substantially. It is possible that in cases where gross growth barely exceeds removals, the inclusion of additional removals from land clearing could tip the balance such that removals exceed growth. However, at present, *GROW* in the sample region shows that current growth (including accumulation of biomass in standing dead trees) is substantially higher than removals.

Region	Gross Growth (million cu. ft/yr)	Removals (million cu. ft/yr)	*GROW*
South Central	9,557.1	5,379.2	−0.78

2.2. *AVOIDEMIT*

AVOIDEMIT is not applicable in this case study as there are no avoided emissions from removal of this roundwood feedstock, or emissions would have happened regardless of the forest roundwood harvest that occurred (i.e., the trees would have been kept in place); thus, *AVOIDEMIT* drops out of the equation for roundwood.

2.3. *SITETNC*

This section develops an illustrative regional approach to estimating default values for *SITETNC* for roundwood feedstock using a retrospective reference point approach. If changes in feedstock demand did not induce land use changes shifting non-forested lands into forests or vice versa, and if non-feedstock C pools were constant at the site of feedstock production during two consecutive measurements, then *SITETNC* would be 0. However, if emissions (or increased sequestration) would occur from the non-feedstock carbon pools at the feedstock production site due to feedstock production and/or removal, *SITETNC* will be positive (or negative). In situations of roundwood removal for wood products or combustion at a stationary source, a certain percentage of logging residue is normally left on site. Thus the onset of increased roundwood removals may alter production site emissions because the corresponding increased input of those residues also occurs, causing higher C stock levels in the detrital pools such as the forest floor. Quantifying these changes is difficult, however, because site-level variability is substantial and because any changes are typically small in comparison to the large C pools involved. Letting the variable *"DETRITAL"* represent the change in detrital pools, where a negative value represents sequestration (i.e., increases to the detrital pool) and a positive value represents emissions (i.e., decreases in the detrital pool), the calculation of *SITETNC* is given by Equation H.4:

$$\boldsymbol{SITETNCroundwood = \frac{DETRITAL}{REMOVALS}} \qquad \textbf{(EQ. H.4)}$$

In order to estimate the change in detrital and soil pools on a regional basis associated with increased roundwood removals, this calculation uses empirical measurements to compare C stocks in these non-feedstock C pools at two points in time. While this baseline approach does allow for the detection of change in these pools, it cannot attribute the specific drivers of change. Therefore, where change in these pools occurred, the calculation used data on estimated roundwood harvest to attribute the measured change to production site detrital pools. This approach, in which trends in C pools are monitored over a predetermined spatial scale, follows the logic of the *GROW* term under a reference point baseline.

When roundwood is harvested, there are changes to C stocks at the site of harvest in detrital forest C pools including coarse woody debris, forest floor C, and mineral soil C. While the forest floor C pool and the relationships between forest harvest practices and soil C responses are increasingly well understood (e.g., Lal, 2005), the impact of harvesting and utilization on mineral soil C is unknown (Buchholz et al., 2013).

Thus, while it is possible that increased roundwood removal and related detrital pool changes may affect the deep mineral soil C pool, quantification of these effects as they relate to roundwood removal are not be discussed here due to a lack of deep soil C data as well as scientific consensus on the issue. Forest floor and coarse woody debris C pools are better understood, and data are available through the USDA Forest Service's FIA program (discussed further in the logging residues case study below).

2.3.1. Data

Removal of roundwood from a forest site has the potential to affect all detrital carbon pools covered in the FIADB, namely above and below ground carbon in seedlings, shrubs and bushes, as well as carbon in stumps, coarse woody debris and litter. As the standing dead C pool is already covered in the *GROW* term, it is not further considered for *SITETNC* to avoid double counting. A major concern with the detrital C pools is that in the FIA dataset, all of them are modeled and based on other measurements and are therefore associated with uncertainties (see Section 2.3.5).

2.3.2. Results

As examined in this case study, the above and below-ground carbon in seedlings, shrubs and bushes, as well as carbon in stumps, coarse woody debris and litter are based on plot-level C models (Smith and Heath, 2008) in all of these estimates. While model outputs for coarse woody debris are close to field-based estimates (Domke et al., 2013), these models were developed for national greenhouse gas inventories and not designed to detect changes on a plot level itself based on a shift in management regimes. Moreover, uncertainties accrue as some detrital C pool estimates rely on model outputs for other detrital pools. For instance, C in stumps and dead roots is currently calculated based on a ratio of down dead to live biomass. If down dead biomass is removed (e.g., for bioenergy applications), this method would underrepresent C in stumps and roots (EPA, 2011).[4] To avoid attributing emissions or sequestration to these C pools as land moves into and out of forest and timberland we base our estimate of change on the change in per acre values of *SITETNC* between FIA inventories rather than on the aggregate amounts.

Results for the Southern regions are given in Table H-3. In the Southeast, 77.9 million tons of roundwood were removed annually and C stocks in detrital pools rose 1.9 million tons per year. These values leads to a *SITETNC* value of −0.024 tons of detrital carbon per ton of roundwood removals. Note that these calculations assume that a contribution to the atmospheric CO_2 stock would be a "positive" emissions flux, while an increase in terrestrial carbon uptake would have a negative sign. Thus, *SITETNC* impacts are negative as sequestration in Southeastern detrital pools increases between the historical reference points utilized.

[4] Dead organic matter in FIA is initially calculated as three separate pools: (1) standing dead trees; (2) down dead wood; and (3) forest floor carbon. Down dead wood includes stumps and roots of harvested trees. Ratios of down dead wood to live tree are used to estimate this quantity.

Table H-3. *SITETNC* Term for the Southeast Roundwood Example (2010 FIA Data).

Region	Detrital Pool Change (million tons/yr)	Removals (million tons/yr)	*SITETNC*
Southeast	1.9	77.9	−0.024
South Central	2.0	99.1	−0.020

2.3.3. Detecting Changes in Management Regimes in Detrital Pools through FIADB Sampling Designs

As described above, it is difficult to attribute change in non-feedstock measured C pools directly to changes in management regime such as increased roundwood production and resulting increased residue contributions to the detrital pool and impacts of residue removal (the latter is discussed in the next section on logging residues). For example, a subset of the FIA plots (e.g., 1/6th to 1/16th) are monitored for these residue pools across a measurement cycle, and only a fraction of these plots might be affected by harvest activities, let alone residue removal. As such, the signal from changed forest management might be lost in the overall noise (meaning that the change in residue C pool stats from the subsample of FIA plots may not be significantly different from 0), particularly if large-scale stochastic disruptions occur such as fires or insect outbreaks. While the latter issue is not of concern for the *GROW* term as long as the regions are held large enough, such stochastic events may affect the larger noise to signal ratio associated with a smaller plot size and smaller relative changes in the affected non-feedstock (detrital) C pools compared with the live biomass pool (e.g., Westfall et al., 2013). For instance, if a region exhibits a 50-year harvest reentry interval for harvest activities and FIA measurements occur in 5-year cycles, around 10% of the C influx to the detrital pools would be removed if: (1) all harvest sites experience residue removal; and (2) all of the residues would be removed. As the reentry interval is 50 years, this signal would occur only in 2% of the measured plots.

In addition to uncertainties derived from imprecision in residue C pool measurements or sampling sizes, another source of uncertainty lies in the conversion factors applied to produce C pool estimates from direct measurements such as computing the bulk density of rotting material (e.g., Russell et al., 2013).

Despite these uncertainties, the measurements of detrital pools developed as part of the *SITETNC* term do provide an estimated baseline value that can be used to monitor the extent to which these pools are changing due to increased roundwood production, and thus the extent to which emissions are occurring from at the feedstock production site as a result of these changes.

2.3.4. Other Detrital Carbon Pools than Woody Debris in FIA

As described above, to allow for assessment of the impact of roundwood removal on all detrital forest C pools, it would be advisable to also include the dynamics of the mineral soil pool. Other pools are expected to be covered by measurements in upcoming FIA P3 sampling designs, and pool dynamics are reasonably well understood with the exception of the mineral soil C pool (Harrison et al., 2010).

2.3.5. Uncertainties and Areas of Future Research

There are several issues when monitoring detrital forest in FIA's assessments, which will require additional efforts to make the approach outlined above a better representation of *SITETNC* for roundwood. First, merchantability of the roundwood resource is determined in large part by market conditions. In strong forest products markets pulp prices may be lower due to high mill residue availability, and more roundwood material is left in the forest. Likewise, in weak forest products markets pulp prices might rise due to a constrained mill residue supply leading to greater recovery from forest harvesting operations. Thus, roundwood utilization is a key component of quantifying the carbon impact of feedstock removal on detrital carbon pools. Second, the uncertainty derived from converting detrital field measurements (e.g., coarse woody debris diameter) to C pool estimates (e.g., coarse woody debris C) adds uncertainty to C pool estimates (Russell et al., 2013). Third, change in management regimes, i.e., the level of roundwood utilization and extraction, is difficult to detect using current FIA sampling designs (Westfall et al., 2013). Fourth, the specific impacts of forest management on the large deep mineral soil C pool are not well understood, a fact which is unlikely to change anytime soon (Buchholz et al., 2013) adding additional uncertainty to any soil C estimates.

In summary, uncertainties in determining roundwood harvest impacts on detrital C pools are associated with the data for all detrital C pools considered here, based in large part on conversion factors and extrapolation methods. Whether monitoring detrital resources strictly through model-based or field-based approaches, there is cumulative error (i.e., sampling error, measurement error, and model error) that should be acknowledged and incorporated into assessments.

3. Illustrative Method for Developing Regional Default Values for Biogenic Attributes: Pacific Northwest Logging Residues

This section develops illustrative regional default values for the use of logging residues, i.e., material that would otherwise have been left on the forest floor as harvest residue, as a feedstock for a stationary source that emits biogenic CO_2, in the Pacific Northwest. It is important to note that this analysis includes data and results for avoided emissions from logging residue feedstock use that is not retrospective in nature: it is based on a literature-based alternative fate counterfactual assessment value which includes decay rates into the future. In an application of the framework that necessitated only retrospective analysis, inclusion of decay rates and other future alternative fate counterfactual assessments could not be included. This alternative fate analysis is included as an alternative method to the modeled detrital pool analysis presented in the Southeast Roundwood section above.

The discussion in this section is based on the assumption that the only action involved is the extraction and utilization of logging residues from already occurring forest harvesting operations[5],

[5] Forest products, in general under current market conditions, are characterized by a joint production function, as many products/materials can be produced from the harvest of a single tree. Firms strive to optimize production to maximize the amount of high-value products (e.g., saw lumber, paper) and minimize the amounts of lower value

and thus the *GROW* term is set to 0. Furthermore, this case study is not completely retrospective as it assumes some additional amount of logging residue harvest that would not have occurred under business-as-usual conditions. In the previous roundwood example, logging residues would ultimately contribute to the detrital carbon pools in *SITETNC*. As such, the methodology employed for logging residue use in this case study assumes that the biogenic feedstock is extracted from *SITETNC* pools, resulting in a positive emission that reflects reduced sequestration in these detrital pools. This is a valid assumption as residues from logging operations would contribute to these pools in the absence of collection and utilization. Since logging residues are assumed to be additional, keeping this emissions impact of biomass removal within the *SITETNC* pool (rather than *GROW*) is justified. Finally, the resulting reduction in woody debris decay emissions in the forest is credited a negative *AVOIDEMIT* value.

3.1. *GROW*

For logging residues in this illustrative application of the reference point baseline, the *GROW* term does not apply because the logging residue feedstock is assumed to taken place due to already occurring harvesting operations therefore not impacting the *GROW* term's growth or removals.

3.2. *AVOIDEMIT*

The *AVOIDEMIT* term does apply for this feedstock because *AVOIDEMIT* represents the emissions that would have occurred at the field site had the feedstock (i.e., logging residues) not been removed for bioenergy. The carbon stocks considered in the context of *AVOIDEMIT* can be termed "detrital" stocks to denote that they are dead and "non-growing." In forests, these detrital feedstocks could include tree tops, branches, and stumps left after a roundwood harvest.

Deciding on an appropriate value of *AVOIDEMIT* requires an assessment of the ratio between the amount of C that is stored long-term on site via leaching into the soil C pool, and the amount of C that would have been emitted to the atmosphere via feedstock decay if the residue were left onsite or emitted to the atmosphere from open-burning onsite (Miner et al., 2014). As some of the C in the residue feedstock would have leached into the forest floor if the residue were not removed, the value of *AVOIDEMIT* should include at least some level of long-term C storage in most cases (discussed below).

3.2.1. *AVOIDEMIT* for Logging Residues in Non-fire-prone Regions

The literature was reviewed in order to assess the degree of long-term C storage on site associated with leaching of C into the soil C pool, in order to estimate appropriate regional values for *AVOIDEMIT* for logging residues. While there is a large scientific literature on wood decomposition rates in U.S. forests (Jandl et al., 2007; Johnson and Curtis, 2001; Jones et al., 2011; Laiho et al.,

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products (e.g., mill or logging residues). While there is some responsiveness to relative price movements (e.g., higher demand and prices for wood pellets may lead to an increased proportion of mill or logging residues going to this use and a decreased proportion going to particleboard or other uses), the elasticity of transformation between outputs may be very inelastic, and even with a negative price some low-value products would still necessarily be produced as a byproduct of the production of higher value products (e.g., sawdust, black liquor).

2003; Smith and Heath, 2002), the fraction of detrital C that will be mineralized and stored long-term in the forest soil remains largely unknown (Buchholz et al., 2013; Nave et al., 2010), and is probably highly site- and management-specific. Deep mineral soil C measurements are not available for FIA plots (Harrison et al., 2010) and measuring deep soil C is difficult (e.g., Johnston et al., 2004): thus, an empirical dataset applicable for smaller spatial scales that can link forest management activities with changes in deep soil C is not currently available (Smith et al., 2012).

The values for *AVOIDEMIT* presented here utilize a non-combustion (not open burn) related *AVOIDEMIT* term of −0.98, which means that 2% of the logging residue would not have been released into the atmosphere from on-site residue decomposition and would instead have entered long-term sequestration in deep soil pools (see Table H-4) (Zanchi et al., 2012). Soil type, microbiological activities, solar radiation reaching the forest floor, land use, or climate can influence the rate of long-term sequestration in soils. While a value of -0.98 is used here, note that changes in mineralization rates and long-term storage have also been observed, but as of yet the drivers of these changes are not understood (e.g., Nave et al., 2010; Pregitzer and Euskirchen, 2004; Zummo and Friedland, 2011).

3.2.2. *AVOIDEMIT* for Logging Residues in Fire-prone Regions

With the exception of the Northeast and North Central regions, all other regions in the United States practice slash burning to varying extents.[6] If current practice entails the burning of all logging residues onsite in slash piles, such that combustion of slash is the baseline, it can be argued that the fraction of carbon remaining from the logging residues following the burning equals 0.06–0.08 for the affected regions. Finkral et al. (2012) found that "on average, burning released between 92% and 94% of the carbon in each slash pile to the atmosphere," while DeLuca and Aplet (2008) discuss the longevity of charcoal C pools under typical U.S. forest floor conditions. Additional research will be required to: (1) produce evidence-based and proven numbers on the long-term fraction of carbon remaining from the logging residues for both combustion and non-combustion related soil C dynamics; (2) identify current slash handling practices across all regions to establish a defensible fraction of carbon remaining from the logging residues including 'slash burning baselines;' and (3) categorize intra-regional ecosystem variations with potentially diverging logging residue baselines such as in the Pacific Northwest that combines forest types with both very high and very low fire frequencies.

Burning of logging residues is the common current practice, and assuming near-complete combustion, the content of C in wood ash is diminutive (e.g., Demeyer et al., 2001) and *AVOIDEMIT* approaches a value of −1 (i.e., −0.98 as indicated in column one of Table H-4). In contrast, less complete combustion of residues leaves more ash behind, thereby changing the balance between emissions to the atmosphere and C stored long-term via leaching (i.e., the 7% difference from a value of −1 (i.e., −0.93) indicated in column two of Table H-4).

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[6] Slash burning is the deliberate and controlled incineration of logging residues onsite to reduce the risk of uncontrolled ignition (Smith et al., 1997).

Table H-4. Estimated *AVOIDEMIT* Values for Logging Residues. Values Were Estimated for Two Management Practices: Without and With Onsite Combustion of Logging Residues. Numbers are uncertain at this point and are presented as placeholders until further research confirms long-term storage of combustion and non-combustion related soil C.

Management Practice	*AVOIDEMIT*
Current management does not combust logging residue on site	−0.98
Current management combusts all logging residue on site	−0.93

3.3. *SITETNC*

In logging residue collection systems, periodic entries to remove harvesting residuals alongside roundwood harvest operations leave the rest of the standing live C pool largely intact in comparison to a roundwood-only harvest. As long as the roundwood harvest is part of the normal operation for the working forests in the source region (and does not represent a new management practice or a change in management intensity), then other impacts on *SITETNC* can be expected to be 0 (Masek et al., 2011). In traditional harvests tree boles are removed while tops and limbs are left on site (Stenzel et al., 1985). The addition of these tops and limbs to the *SITETNC* C pool would constitute sequestration to the pool (negative emissions flux to the atmosphere). However, with these tops and limbs being collected and utilized as a biogenic feedstock that negative addition to *SITETNC* does not occur and so when compared to traditional practices declines in litter, dead wood, and soil C stocks will result. In this case, where a transition from a traditional practice of leaving tops and limbs on site to a logging residue collection system, the *SITETNC* impact is equal to 100% of the residue portion of the harvest removed. When *SITETNC* is considered together with *AVOIDEMIT*, the combined assessment factor in the case where the logging residues would not have been burned is 0.02 (−0.98+1.00) representing the 2% of logging residue carbon that would have remained long term in the soil.

Table H-5. Estimated *SITETNC* Values for Logging Residues.

Management Practice	*SITETNC*
Proportion of logging residues removed from the forest	+1.00

4. Illustrative Method for Developing Regional Default Values for Biogenic Attributes: Corn Belt Corn Stover

Developing regional landscape attribute values for many non-traditional agriculture-derived biogenic feedstocks including corn stover as well as switchgrass, hybrid poplar, and other dedicated energy crops using a retrospective reference point baseline is currently challenging. The main reason for this is that these feedstocks (unlike traditional crops used for liquid biofuel production) have either not been used traditionally for large scale stationary source energy production (e.g., stover) or they have not been commercially cultivated to the extent that there is observed historical data at a regional or national scale (e.g., dedicated energy crops). Without such datasets, it is difficult to estimate the alterations in management practices or in land usage and the associated biogenic C impact profiles when the feedstock is collected or produced for energy. In the future, it may be possible to calculate more concise *SITETNC* values with a retrospective reference point baseline using historical data providing that there is widespread use of and data collection pertaining to the feedstock of interest.

The discussion in this section focuses on possible ways to estimate *AVOIDEMIT* and *SITETNC* values for corn stover residues if needed before such datasets are available (the *GROW* term is not relevant to this feedstock category). The following section delves further into the challenges of producing similar estimates for other agricultural and dedicated energy crops using this baseline approach.

4.1. *GROW*

For crop residues created from annual crops such as corn stover, the carbon sequestered by the annual growth of the feedstock is counterbalanced by the carbon in the feedstock at harvest, hence *GROW* is set to 0.

4.2. *AVOIDEMIT*

The *AVOIDEMIT* term reflects the avoided emissions, those that would have occurred anyway from the field site without the removal of the biogenic feedstock for bioenergy use (i.e., decay). The fate of agricultural residues is different from forest residues for a number of reasons including differing decay rates, no commonly measured long-term detrital carbon pools, and site-specific management. That said, there are similarities between agricultural and forest residues. For example, when agricultural residues are burned, an unburned fraction remains. The unburned fraction of agricultural feedstocks varies by feedstock (e.g., see EPA, 1994, 2013). However, agricultural residue burning did not contribute to long-term carbon storage in a 31-year study by Rumpel (2008).

For agricultural crop residues such as corn stover in this illustrative calculation, if the residues had not been removed from the field, they would have decomposed, with all the carbon in the residues oxidizing before the start of the next production year. For example, leaving crop residues in the field was found not to contribute significantly to soil carbon in a study by Gale and Cambardella (2000). Tillage practices and fertilizer application had a larger effect on soil carbon change when compared to residue removal in a 30-year study by Reicosky et al. (2002) and in a study by Clapp et al. (2000). Dick et al. (1998) also found that tillage and rotation played a larger role in soil carbon change than did residues. Residues can, however, contribute to soil organic matter, provide a physical buffer, improve the chemical, physical and biological properties of the soil, reduce raindrop impact and wind shear, reduce erosion, and increase yield (under certain conditions) (Andrews, 2006; FAO, 2004). The magnitude of these effects is highly variable at a national scale. Variables such as crop type, growing conditions, and agricultural practices all affect the potential quantities of residue converted to soil carbon (Andrews, 2006). USDA recommendations for appropriate residue removal for biofuel production suggest that removal rates be based on regional yield, climatic conditions, and cultural practices with no specific national rates provided (Andrews, 2006).

Under a truly retrospective baseline approach, *AVOIDEMIT* could be assigned a value of −1 (i.e., all emissions would have occurred anyway). However, given data limitations on historic corn stover removals, this case study evaluates the net landscape emissions effect of a management switch from conventional corn production to corn production with residue harvesting using biophysical processing modeling coupled with relevant information on regional crop-mix and management data. The approach compares the soil carbon profiles of two different management regimes, and implicitly includes the portion of emissions from feedstock decomposition for each scenario. Thus, *AVOIDEMIT* is given a value of 0 for this hypothetical case study and all landscape emissions impacts are included in the *SITETNC* term (discussed in detail below). This approach also acknowledges the variability and inherent uncertainty in the contribution of crop residues to soil carbon at the national scale. It is noted that specific residue removal rates, if such data is gathered and compiled nationally, might influence the estimated contribution of crop residues to soil carbon (and other factors) under certain conditions.

4.3. *SITETNC*

This section discusses the data needs for deriving net landscape emission estimates for corn stover used in stationary sources for energy and then presents the methods used in this appendix to develop illustrative values for use in the illustrative case study presented in Appendix I.

4.3.1. Data and Methods

In an evaluation of corn stover, information on management activities, whether land use and/or management activities have changed, and the associated biogenic CO_2 flux profile would be needed. For example, one would need measures of what corn stover yield was and whether there were alterations in management that caused changes in soil carbon following corn stover harvest. Such information could be based on data collected by localized or national farm surveys such as the USDA ERS ARMS survey (if available), state-level Agricultural Extension Service reports (if available), the use of estimates from models with soil and GHG modeling capabilities, some mixture of agronomic experimental data and field measurements, or a combination of these methods.

Management activities such as increased stover removal and related soil carbon impacts are currently not captured in national datasets and can vary significantly by soil type, environmental condition, and management profile. Therefore for this illustrative framework application using the retrospective reference point baseline to evaluate corn stover impacts in the Corn Belt region, the *SITETNC* equation term uses a proxy that was generated by using results from the DAYCENT model in conjunction with data from USDA on the prevalence of particular tillage types by region and fertilizer use by crop and region (USDA ERS, 2013). These merged datasets were then applied to statistical meta-models (akin to response surface regressions) developed by Dr. Stephen Ogle of the Natural Resource and Ecology Laboratory to estimate soil carbon and nitrous oxide emission changes between different scenarios (with and without corn stover removals). This *SITETNC* calculation method differs from other methods used for agriculture- and forestry-derived feedstocks for which there is historical data that can be used to assess changes between two reference points in the past. For illustrative purposes this method is included, despite not being truly retrospective. The rest of this section briefly describes how the proxy values are generated and a detailed description of how the meta-models were derived and applied is provided in an Addendum to this section.

The *SITETNC* estimate reflects the change in carbon when corn stover collection occurs on land assumed to have previously been used to grow corn without the corn stover being removed. This *SITETNC* term calculation accounts for the difference in the amount of sequestered carbon on a CO_2-equivalent basis per ton feedstock between these two scenarios. Also included in the discussion below is calculation of related nitrous oxide (N_2O) emissions for use as a sensitivity in the case study appendix.

The first step includes estimation of sequestration and emissions from the land under corn production in both the without and with corn stover removal scenarios. These calculations required development of estimates of initial corn stover yields (estimated quantity of residues produced per acre) and initial soil carbon profile and N_2O emissions under corn production without stover removal. Then, the soil carbon and N_2O emissions profile or corn production was updated assuming management changes associated with corn stover removal. Appendix D of the Beach and McCarl (2010) RFS2 report describes calculation of the quantity of residues produced per acre by crop and provides citations for what was used for the percent of total residues that could be sustainably removed (Graham et al., 2007; Perlack et al., 2005). As a general rule, USDA National Resources Conservation Service (NRCS) recommends that about 30% residue cover is adequate to control soil erosion (Maung, 2007). Removable residue values used in the Forest and Agriculture Sector Optimization Model with Greenhouse Gases (FASOM-GHG) are calculated by adjusting the residue production per acre based on the harvestable percentages provided in Graham et al. (2007) and Perlack et al. (2005) which consider the effects of erosion and runoff. This approach uses a maximum percentage removal of residues,[7] which vary by crop and tillage.

The corn stover yield and related DAYCENT emissions estimates were developed in conjunction with regional dryland and irrigated crop budgets in the FASOM-GHG model. These budgets were developed over the years in FASOM-GHG based on farm budget data from regional extension services and publicly available USDA ERS datasets. In turn those data were disaggregated so that they contained different tillage and fertilization levels using runs from the DAYCENT model and budget data on costs from USDA NRCS. The budget data were updated to 2010 in terms of yields and nitrogen utilization based on USDA ERS ARMS data and USDA annual agricultural statistics at the state level.

With this information the two scenarios are developed:

- **Corn without Stover Harvested (*$CropEmissioncrop_{r,corn}$*).** Emissions and sequestration estimates in the without stover removal scenario includes the carbon that resides in the soil per acre when stover is left on site. The land use associated with stover removal is assumed to not change. This calculation involved usage of DAYCENT results on carbon sequestration rates and N_2O emissions in metric tons CO_2 equivalent per acre.

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[7] Many site specific factors associated with the sustainable removal of residue (e.g., crop type, soil type, soil fertility, slope, and climate) affect which geographic regions are suitable for crop residue removal. Detailed modeling of these factors was beyond the scope of this analysis.

- **Corn with Stover Harvested (*CropEmissioncrop$_{r,stover}$*)**. Consideration of emissions and sequestration estimates when stover is removed necessitated estimates of soil carbon stock changes and N_2O emissions. The soil carbon sequestration and N_2O estimates were derived from DAYCENT. The yield of harvestable corn stover was based on USDA NRCS estimates were deduced from the estimated amount of stover that needed to remain on site to limit erosion. The change in N_2O emissions also considered the need for additional nitrogen to replace the nutrients removed when the stover was removed.

The second step involves solving for the *SITETNC* estimate per ton of feedstock by subtracting the carbon sequestration and N_2O emissions for the average acre with corn stover removed from the average acre without stover removed. With this calculation, a positive result indicates an increase in emissions or a decrease in sequestration. These terms and results are in terms of net emissions/sequestration per acre of feedstock grown in metric tons of CO_2 equivalent:

$$\mathbf{SITETNCperacre_{r,stover} = CropEmissioncrop_{r,corn} - CropEmissioncrop_{r,stover}} \qquad \textbf{(EQ. H.5)}$$

The data were transformed to a per ton feedstock amount by dividing by regional per acre yields of corn stover. These are in units metric tons of CO_2 equivalent emissions/sequestration per short ton (2000 lbs) feedstock. Note that this approach does not capture additional land use change or management emissions that are attributable to the increased residue demand. That is, crop production area is held constant between the scenarios, so no land use change or emissions associated with crop switching are captured.

4.3.2. Results

The illustrative results presented in Table H-6 below reflect the annual average *SITETNC* values with and without N_2O emissions expressed in metric tons of CO_2e per ton of feedstock for corn stover in the Corn Belt.

Table H-6. *SITETNC* per Ton of Feedstock for Corn Stover in the Corn Belt.

Feedstock	Region	SITE_TNC (carbon only) (metric tons CO_2e per ton feedstock)	SITE_TNC (carbon + nitrous oxide) (metric tons CO_{2e} per ton feedstock)
Corn Stover	Corn Belt	+.0026	+0.0123

5. Supplemental Information

This section provides supplement information on the methods used to develop the illustrative *SITETNC* values for corn stover in the Corn Belt.

5.1. Details on the Meta-models Used to Derive Soil N_2O and Soil Organic Carbon Stock Changes for *SITETNC*

Meta-models were developed to estimate soil organic carbon stock changes and soil nitrous oxide emissions associated with various management alternatives. The data were generated using the

DAYCENT ecosystem model, and were used to derive linear-mixed effect models that were incorporated into the FASOM-GHG model. This report provides information on how the meta-model were derived and applied.

5.1.1. DAYCENT Model

The DAYCENT biogeochemical model is used to estimate crop grain and straw yields (including corn stover), soil organic carbon stock changes, and soil nitrous oxide emissions for different crops and management scenarios. DAYCENT (Del Grosso et al., 2006; Parton et al., 1998) is a process based model of intermediate complexity, and simulates the influence of management practices and other events, such as fire, grazing, cultivation, and fertilizer additions, on carbon and nutrient dynamics in plant-soil systems. The model requires several inputs, including soil texture; current and historical land use; and daily maximum/minimum temperature and precipitation data. Plant growth is a function of soil nutrient and water availability, temperature, and plant specific parameters, such as maximum growth rate, minimum and maximum biomass carbon to nutrient ratios, and above ground versus below ground carbon allocation. Soil organic carbon is represented as three pools that are kinetically-defined with slow, intermediate and long turnover times. Carbon is transferred from dead biomass into the soil organic carbon pools, and over time will decompose and return CO_2 to the atmosphere. Nitrogen gas emissions (nitrous oxide, nitrogen oxides, dinitrogen gas) from nitrification and denitrification are controlled by soil mineral N levels (nitrate and ammonium), water content, temperature, pH, plant N demand, and labile carbon availability. Nitrate leaching losses are controlled by soil nitrate availability, saturated hydraulic conductivity, and water inputs from rainfall, snowmelt, and irrigation.

The ability of DAYCENT to simulate yields, soil organic matter changes, nitrous oxide emissions, and nitrate leaching for conventional crops (e.g., corn, wheat, barley) has been validated by comparing model outputs with measurements from major commodity crops and grassland systems in North America (David et al., 2009; Del Grosso et al., 2005; Del Grosso et al., 2008). The model is also shown to simulate biomass yields reasonably well for switchgrass grown at different sites in Illinois (Davis et al., 2010) and the impact of nitrification inhibitors on nitrous oxide emissions (Del Grosso et al., 2008). DAYCENT has been applied for simulation of soil greenhouse gas fluxes at scales ranging from plots to regions and the globe (Del Grosso et al., 2010; Del Grosso et al., 2005). The model has been used since 2005 to estimate nitrous oxide emissions from agricultural soils in the U.S. National Greenhouse Gas Inventory compiled by the EPA, and reported annually to the United Nations Framework Convention on Climate Change (Del Grosso et al., 2010; Del Grosso et al., 2006; EPA, 2012).

5.1.2. DAYCENT Simulations

DAYCENT is used to simulate cropping systems at the county scale across the contiguous United States. To compile model inputs, the centroid for the largest cluster of cropland in each county is identified based on National Land-Cover Dataset (Homer et al., 2007). For the county-scale simulations, model inputs for daily weather are based on the DAYMET dataset for the county centroid. DAYMET (Thornton and Running, 1999; Thornton et al., 1997) generates daily surface precipitation, temperature, and other meteorological data at 1 km^2 resolution using weather station observations and an elevation model. Soil properties were acquired from the dominant STATSGO (State Soil Geographic Database) (USDA NRCS, 1997) map unit at the centroid cropland in a county. Hydraulic properties are calculated from STATSGO surface texture class and Saxton et al. (1986) hydraulic properties calculator.

Land management data for annual crops are compiled at the agricultural region level (McCarl et al., 1993). Most states correspond to one of the 63 regions, except a few states that were further divided into two or more regions. Data for average fertilization rates, timing of planting/harvest, and crop rotation schedules are obtained from various sources based on farmer surveys and fertilizer sales data (EPA, 2012).

Management alternatives included adoption of conservation tillage practices; land use change to cropland management from grassland and forest land; reducing nitrogen fertilizer rates; applying organic fertilizers; varying timing of fertilization events between fall and spring; and applying fertilizer with nitrification inhibitors. The simulations are conducted by randomly combining the management options for these practices in a Monte Carlo analysis with 1000 simulation in each region. DAYCENT simulated direct N_2O emissions, volatilization (nitrogen oxides, ammonia) and nitrate leaching. Indirect soil nitrous emissions are estimated based on converting 1% of volatilized nitrogen and 0.75% of leached/runoff nitrogen into N_2O (IPCC, 2006).

5.1.3. Meta-models

Meta-models for soil organic carbon stock changes, direct and indirect nitrous oxide emissions are derived for crops in each region based on the simulation results. Meta-models are also derived for crop grain and straw yields. The meta-models are developed using a linear mixed-effect modeling approach (Pinheiro and Bates, 2000). The potential set of model predictors include nitrogen fertilization rates, timing of fertilizer application, use of nitrification inhibitors, mean temperature, mean precipitation: potential evapotranspiration ratio, soil texture, residue removal rate, tillage practice, and land use change. Only variables meeting an alpha level of 0.05 are included the model; additional variables is required to reduce the Akaike Information Criteria by at least a value of 2 digits (Akaike, 1973; Burnham and Anderson, 2002). The variables included in each model vary by agricultural management region. The models are incorporated directly into the FASOMGHG economic modeling framework.

Meta-models are developed to estimate the average change in soil organic carbon stocks over increments of five year time periods in the surface soil (20 cm). The resulting estimates are in metric tons C/ha, and can be annualized by dividing by 5. The annualized data can be converted into CO_2 equivalents using the conversion factor, 44/12. Following conversions, the value can be multiplied by the area of the crop or grass to obtain the total change in SOC stocks for the feedstock.

N_2O emissions directly emitted in the field are estimated using a meta-model, and also N that is lost from a managed field through volatilization or leaching/runoff, and later emitted as N_2O in waterways or following atmospheric deposition in soils. IPCC (2006) recommends that N leaching is not included in the estimate of indirect N_2O emissions if annual precipitation minus potential evapotranspiration does not exceed field water holding capacity, with the possible exception of irrigated lands. The first step is to determine which areas will have nitrate leaching according to the IPCC guidelines. A logit model is developed to determine if leaching will occur with irrigation in the regions that are too dry for leaching without irrigation.

The meta-model results for the direct N_2O models, nitrate leaching/runoff and volatilization are in natural log transformed space and require a backtransform. Units are gNO_3-N/m^2/yr for the nitrate leaching/runoff, and gN-NH_3+NO_x/m^2/yr for volatilization. To obtain the indirect N_2O emissions, the leaching and volatilization estimates are multiplied by the indirect emission factors from IPCC, which are 0.0075 kgN_2O-N/$kgNO_3$-N/yr for nitrate leaching/runoff, and 0.010 kgN_2O-N/$kgNH_2$-N+NO_x-N/yr for volatilization (IPCC, 2006).

The direct and indirect emission results are in kgN_2O-N/m^2/yr, and are converted into kgN_2O/m^2/yr using the conversion factor, 44/28. In turn, the estimate can be converted into CO_2 equivalent using 310 or other alternative GWP conversion factors. Following conversions, the resulting value is multiplied by the area of crop or grass to obtain the total direct N_2O emissions on an annual basis in CO_2 equivalent units.

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