Appendix L: Illustrative Forestry and Agriculture Case Studies Using a Future Anticipated Baseline

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1. Introduction

This appendix demonstrates the functionality of the future anticipated baseline approach through three illustrative region- and feedstock-specific case studies. These case studies use the baseline scenarios constructed in Appendix K as the basis for comparison of alternative biogenic feedstock production scenarios per specific feedstocks and specific regions. The application of the future anticipated baseline approach within these case study constructs allows for the calculation of illustrative values for the pertinent framework equation terms and ultimately generation of illustrative biogenic assessment factors (*BAF*) specific to the individual case study parameters and assumptions.

Results show aggregate emissions estimates on a specific regional scale per case study. Results can be interpreted as the projected emissions intensity of specific biogenic feedstocks consumed at existing or anticipated stationary sources across multiple baseline projections of biogenic feedstock consumption. However, results do not reflect the net emissions *contribution* of a particular feedstock within a particular region but rather illustrate potential net biogenic emissions effects *associated with increased consumption* of a specific feedstock in a specific region under specific conditions. To maintain consistency with the reference point approach, region- and feedstock-specific simulation scenarios were developed to isolate the landscape-level carbon-based emissions fluxes related to a demand shift for an individual feedstock relative to the AEO Reference baseline (as presented in Appendix K).

The three case studies are:

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

This appendix first provides an overview of the methods used to construct the case study parameters, an explanation of the how landscape-level biogenic emissions fluxes are mapped to *BAF* equation terms, a discussion of how to interpret results (using different assessment methods), and a presentation of illustrative case study results and analysis.

The values derived in this appendix are intended to illustrate the future anticipated baseline approach and do not reflect EPA findings in the context of specific policies or programs. As with all modeling studies, a number of uncertainties are present in the baseline assumptions and parameters adopted for this analysis. These uncertainties include historical input data, future environmental conditions and the biophysical emissions accounting parameters, future economic or policy conditions, and technological growth (both for agricultural/forestry feedstock yield and commodity processing technologies). However, model projections provide key insight into the potential market and land use consequences of possible shifts in the demand for biogenic feedstocks at stationary sources.

2. Method and Parameters Used to Calculate the Illustrative *BAF*s Using the Future Anticipated Baseline Approach

The intertemporal optimization approach used in these illustrative case studies captures investment behavior under anticipated changes in feedstock demand; thus, land management responds in advance of an anticipated change. This approach allows for a depiction of land use investment/management over the long term, which provides an improved projection of landscape-level biogenic CO_2 emissions under anticipated changes in biogenic feedstock consumption than static (one-time) models or recursive dynamic models that do not react to future expectations.

Ultimately, numerous assumptions and parameters can be varied to establish future anticipated baselines that differ from those presented here and in Appendix K. Furthermore, there are numerous possibilities for creating alternative feedstock scenarios relative to a future anticipated baseline. The primary goal of this appendix is to illustrate how the future anticipated baseline approach could be applied in practice to assess landscape-level emissions effects related to changes in demand for individual feedstocks. The secondary objectives of this appendix are to evaluate the potential direction and magnitude of biogenic CO_2 emissions from increased regional feedstock consumption, using the modeling assumptions and baseline constructs as presented in Appendix K.

2.1. Case Study Methods

Each feedstock case study was developed using the same underlying methodology. Each feedstock scenario is evaluated relative to the three alternative baseline scenarios, as introduced in Appendix K (Zero Biomass, Constant Biomass [existing sources in 2009], and AEO Reference). For each feedstock case study, the regional emissions intensity of additional biogenic feedstock consumption (additional biogenic CO_2 emissions divided by additional biogenic feedstock CO_2) is computed, similar to the approach outlined in Appendix K and described in more detail below.

Each of the case studies begins with regional biomass consumption trajectories from the AEO Reference baseline and then requires an additional 1 million short dry tons of specific biogenic feedstock consumption in the region under consideration. This additional biomass requirement is phased in linearly, beginning with 250,000 short dry tons in the 2015 simulation period, reaching 1 million tons in 2030. The feedstock requirement is phased in over time under the conservative assumption that it could take time for a new facility or demand point to build up a steady supply source of one particular feedstock given regional market dynamics. The additional biomass requirement is then held constant for the remainder of the simulation horizon[1] and must be met by the case study feedstock only. For the SE roundwood case, for example, the additional biomass requirement must come exclusively from hard and soft roundwood. This constraint is maintained throughout the simulation horizon to isolate the emissions effects of increased demand for a specific feedstock over the long term.

Comparison of the 1 million ton increased feedstock consumption scenario to the AEO Reference baseline scenario can be interpreted as the *marginal* effect of a new source of consumption that is fueled by a single feedstock, relative to the AEO Reference anticipated baseline. This increased consumption could be thought of as the estimated marginal effect of the additional demand from a stationary source that is expected to consume approximately 1 million tons of biogenic CO_2 annually for onsite energy generation over the long term.

Comparison of the 1 million ton increased feedstock scenario to the Zero Biomass baseline scenario provides an estimate of the *average* biogenic CO_2 emissions effect for all existing and planned biogenic feedstock consumption within a region (as defined by the eGRID/EIA dataset-derived 2009 existing users and AEO Reference baseline anticipated new users) plus the additional

[1] The 2012 Annual Energy Outlook projections do not extend past 2030; thus, biomass consumption shock is held constant after this simulation period.

feedstock-specific requirement from the case study. For this comparison, the feedstock scenarios were constructed in exactly the same way (same volumes, same feedstocks), with the anticipated baseline feedstock portfolio exactly matching the AEO Reference baseline simulation results over time. The difference here is that biogenic CO_2 emissions intensity metrics are computed relative to the Zero Biomass simulation results. Thus, the numerator represents the net change in regional projected emissions (Feedstock Case Study − Zero Biomass), while the denominator represents regional biogenic CO_2 consumption (AEO Reference baseline biomass plus additional feedstock requirement).

Another possible method is the *augmented average* approach.[2] Comparison of the 1 million ton increased feedstock scenario to the Constant Biomass baseline can be interpreted as the *augmented average* biogenic CO_2 emissions effect of planned expansion in biogenic feedstock consumption (as defined by the AEO Reference baseline) above the eGRID/EIA dataset-derived 2009 existing users, plus the additional feedstock specific requirement from the case study. Essentially, this is the same methodology as the comparison to the Zero Biomass baseline, but all calculations are relative to an anticipated baseline that holds biomass consumption fixed to observed levels in 2009.

Illustrative equation term and estimated *BAF* results using the marginal and average methods above are presented for each case study.

2.2. Case Study Parameters

All feedstock case studies are simulated over an 80-year time horizon (2000–2080) to capture investment dynamics in the forestry sector over this period. The results are computed using key outputs for the 2010–2060 time horizon (in 5-year timesteps), which provides a 50-year time frame for evaluating land use and biogenic emissions changes (and avoids any terminal effects that may affect results in the last few time periods of results). Results generated within this overall time frame can be aggregated and evaluated in different ways (e.g., the *BAF* can be constructed for 10- to 50-year time frames as desired), and the 50-year mark should not be interpreted as an EPA decision on applying time frames in the contexts of specific programs and policies. The spatial scale of these regional case studies is represented by the 11 primary agroforestry regions of FASOM-GHG. Additional FASOM-GHG modeling details are provided in the Supplemental Information section at the end of this document.

Although FASOM-GHG offers full GHG accounting options (including N_2O and CH_4 emissions from crop and livestock operations), this study focuses on changes in landscape-level biogenic CO_2 only (though a sensitivity evaluating the impact of including N_2O is included in this analysis). This approach includes carbon in agricultural and forestry soils, and carbon stored in forest and agricultural biomass (additional details provided below).

[2] Discussed here as a possible method, but this method was not employed to avoid further complexity, as many different methods could be discussed and employed using a future anticipated baseline approach. Therefore, the illustrative results tables do not include this category.

3. Mapping and Interpreting Future Anticipated Baseline Data and Illustrative Results

This section presents which FASOM-GHG data components are mapped to *BAF* equation terms as well as how *BAF* equation terms are calculated using these data over a specified simulation time horizon. Specifically, FASOM-GHG projections are used to derive representative values for regional net growth (*GROW*), total net carbon change on the feedstock production region (*SITETNC*), and avoided emissions from feedstock harvest or collection (*AVOIDEMIT*) in each simulation period. These terms are aggregated into a net biogenic emissions (*NBE*) term, which is used along with the total additional biogenic CO_2 (calculated directly from the feedstock-specific biomass constraint) as a representative potential gross emissions (*PGE*) value to derive an estimated *BAF*.

A major difference in the illustrative *BAF* terms generated with the retrospective reference point and the future anticipated baseline approach is that the equation terms (*PGE, GROW, SITETNC, AVOIDEMIT*, and *NBE*) as defined and applied within the future anticipated baseline approach do not represent the absolute emissions associated with the terms but rather the additional, or relative, emissions compared with an alternate potential future.

3.1. FASOM-GHG Data Component Mapping to *BAF* Terms

Deriving *BAF* equation term values from FASOM-GHG output data components involves aggregating the various emissions components into a single value. Table L-1 lists specific carbon-based GHG flux categories from FASOM-GHG simulations and the *BAF* equation term associated with each carbon-based GHG flux account. Note that non-CO_2 emissions from crop and livestock management, carbon stored in wood products, and fossil fuel emissions from land management are not included in this analysis.

Table L-1. FASOM-GHG Emissions Components Matched with *BAF* Equation Terms.

FASOM-GHG Emissions Component	Southeast Roundwood	Pacific Northwest Logging Residues	Corn Belt Corn Stover
Agricultural LUC and Soil Management Carbon Flux	*SITETNC*	*SITETNC*	*SITETNC*
Logging Residue Decay Flux	*AVOIDEMIT*	*AVOIDEMIT*	*AVOIDEMIT*
Afforestation Harvest Flux	*GROW*	*GROW*	*SITETNC*
Afforestation Tree Carbon Flux	*GROW*	*GROW*	*SITETNC*
Existing Forest Harvest Flux	*GROW*	*GROW*	*SITETNC*
Existing Forest Tree Carbon Flux	*GROW*	*GROW*	*SITETNC*
Afforestation Litter and Understory Harvest Flux	*SITETNC*	*SITETNC*	*SITETNC*
Afforestation Soil Carbon Flux	*SITETNC*	*SITETNC*	*SITETNC*
Afforestation Litter and Understory Carbon Flux	*SITETNC*	*SITETNC*	*SITETNC*
Deforestation Soil Carbon Flux	*SITETNC*	*SITETNC*	*SITETNC*
Existing Forest Litter and Understory Carbon Flux	*SITETNC*	*SITETNC*	*SITETNC*
Existing Forest Litter and Understory Harvest Flux	*SITETNC*	*SITETNC*	*SITETNC*

FASOM-GHG Emissions Component	Southeast Roundwood	Pacific Northwest Logging Residues	Corn Belt Corn Stover
Logging Residue Carbon Flux	*SITETNC*	*SITETNC*	*SITETNC*
Existing Forest Soil Carbon Flux	*SITETNC*	*SITETNC*	*SITETNC*

Details about the underlying input data for the above FASOM-GHG elements and how they are calculated in the model are included in the Supplemental Information section in this appendix.

3.2. Potential Gross Emissions (*PGE*)

Because the *BAF* as calculated using the future anticipated baseline approach is a measure of emissions intensity, *PGE*, which also varies by time (t), is the estimated biogenic feedstock consumed (in terms of CO_2) in the case study ("*CS*") that is additional to the estimated biogenic feedstock consumed (in terms of CO_2) in the alternate baseline ("*AB*"):

$$PGE_t = \left(BIOGENIC\_CO2_{"CS",t} - BIOGENIC\_CO2_{"AB",t}\right) \quad \textbf{(EQ. L.1)}$$

3.3. Net Growth (*GROW*)

Similar to the retrospective reference point baseline approach, the future anticipated baseline treats *GROW* as the net landscape biogenic CO_2 growth. The forest $GROWTH_{i,"CS",t}$ is indexed by i to represent biogenic emissions fluxes contributing to *GROW* from Table L-1, representative scenario "*CS*" for the case study (or alternative baseline, "AB"), and t for the time period. The following equation represents the calculation of $GROW_t$, where the i index specifically represents the individual biogenic CO_2 fluxes from the SE roundwood column of Table L-1 labeled "*GROW*" (afforestation harvest flux, afforestation tree carbon flux, etc.) It should be noted that the fluxes considered in set i include both forest growth and removals, thus yielding a net growth value for each time period, t. Under this approach, each flux account is the difference between the simulated values for the feedstock case study scenario ("*CS*") and the alternate baseline ("*AB*") for all time periods.

$$GROW_t = \sum_i \left(GROWTH_{i,"CS",t} - GROWTH_{i,"AB",t}\right) \quad \textbf{(EQ. L.2)}$$

3.4. Total Net Change in Site Emissions (*SITETNC*)

SITETNC represents the difference in landscape-level biogenic CO_2 emissions fluxes not directly related to the actual biogenic feedstock growth (for each time period in the simulation). This factor includes changes in carbon stored in soils, non-harvested biomass, and potentially other pools. The change in site carbon, $SITE_{k,"CS",t}$, is the sum of a set of k biogenic CO_2 components from the SE roundwood column of Table L-1 labeled "*SITETNC*" for the case study scenario ("*CS*") in time period t. The following equation illustrates how periodic *SITETNC* values are computed under the future anticipated baseline framework as the relative difference in emissions between the case study, "*CS*," and an alternative baseline, "*AB*," for each time period, t.

$$\boldsymbol{SITETNC_t = \sum_k \left(SITE_{k,"CS",t} - SITE_{k,"AB",t}\right)} \qquad \textbf{(EQ. L.3)}$$

3.5. Avoided Emissions (*AVOIDEMIT*)

A similar logic follows for *AVOIDEMIT. AVOIDEMIT* represents the avoidance of estimated biogenic emissions that could have occurred on the feedstock landscape without biogenic feedstock removal. In the context of the future anticipated baseline approach, *AVOIDEMIT* represents the relative difference in avoided biogenic emissions between scenarios. Each "*AVOID"* term in equation 4 below represents the avoided biogenic emissions within a particular scenario. Letting $AVOID_{h,"CS",t}$ represent the sum of the set of *h* biogenic CO_2 components from the Southeast roundwood column of Table L-1 labeled *AVOIDEMIT*, for the case study scenario("*CS*") in time period *t.* The following equation illustrates how periodic *AVOIDEMIT* values are computed under the future anticipated baseline framework as the relative difference in emissions between the case study ("*CS*") and an alternative baseline ("*AB*") for each time period, *t*.

$$\boldsymbol{AVOIDEMIT_t = \sum_h \left(AVOID_{h,"CS",t} - AVOID_{h,"AB",t}\right)} \qquad \textbf{(EQ. L.4)}$$

3.6. Net Biogenic Emissions (*NBE*)

NBE represents the difference in biogenic landscape-level CO_2 emissions (emissions from harvesting and using the biogenic feedstock) between scenarios (calculated as the sum of all landscape-level CO_2 emissions). This is represented as:

$$\boldsymbol{NBE_t = GROW_t + SITETNC_t + AVOIDEMIT_t} \qquad \textbf{(EQ. L.5)}$$

3.7. Biogenic Assessment *Factor (BAF)*

Thus, the biogenic assessment factor is ratio of the net biogenic emissions (NBE_t) to the potential growth emissions (PGE_t), or simply put:

$$\boldsymbol{BAF_t = {}^{NBE_t}/_{PGE_t}} \qquad \textbf{(EQ. L.6)}$$

4. Guide to the Case Studies

4.1. Understanding the Illustrative Results

The illustrative results provided below for the three case studies include positive and negative values. Positive values indicate a net flux of emissions (harvest or land use change emissions outweigh biogenic CO_2 sequestration on the landscape), whereas negative values indicate net sequestration (biogenic CO_2 sequestration on the landscape outweighs harvest or land use change emissions). However, determination of how and whether negative values would be applied in practice would depend on the policy or program being analyzed.

BAF results can be illustrated in a variety of contexts, relative to different counterfactual scenarios:

- **Marginal and average user effects**—As discussed in the Methods Section above, the average, augmented average, and marginal *BAF* results are a function of the comparison between the specified anticipated baseline scenario (Zero, Constant and AEO Reference) and the case study increased feedstock scenario.

- **Cumulative and per-period calculations and values**—Per-period values, calculated using the formulas from the section above, illustrate *BAF* values specific to an individual point in time. By using intertemporal models, these periodic *BAF*s can vary widely from period to period as land management and forest harvest intervals adjust to the new biomass demand shock. This explains the variable nature of the periodic calculations. A 2015–2060 average is calculated to represent the average periodic *BAF* over the entire time frame of the analysis. Cumulative *BAF*s are calculated by taking the cumulative value of each term in the *BAF* equation over time. The cumulative value offers insight into potential anthropogenic biogenic carbon-based emissions effects over a specified future time horizon relative to the future anticipated baseline, whereas a single value at a point in time only offers insight into periodic deviations from the baseline. Calculation of the *BAF* using cumulative and average values can smooth out the fluctuations in equation terms per period and provide a more stable estimate of net biogenic emissions over time.

Using the Zero versus the AEO or Constant Biomass baseline as the basis of analysis led to different *BAF* values. The Zero Biomass baseline comparison to the case study projection captures all anticipated biomass users, whereas the Constant Biomass comparison focuses on new users. Depending on the policy application of the framework, either of these approaches may be more appropriate. Also, the means for considering the results over time (averaged per-period *BAF*s versus cumulative) led to different *BAF* values. Per-period values, calculated using the formulas from the section above, illustrate *BAF* values specific to an individual point in time, which might be useful in some policy applications but not relevant for others. Given the nature of modeling methods employed, periodic *BAF*s can vary widely from period to period as land management and forest harvest intervals adjust to the new biomass demand shock.

The supplemental data and information section provides the illustrative results and discussion for the various feedstock- and region-specific case studies. Data presented in this supplemental section include projected equation term values for each simulation period for emissions fluxes and cumulative emissions, using the average and marginal counterfactual approaches.

4.2. Overview of the Illustrative Results

Table L-2 provides illustrative values for *NBE* and the *BAF*s for each of the three case studies. These values are based on cumulative emissions totals for a simulation horizon that extends to 2060. In each case, *NBE* and *BAF* values are calculated relative to the Zero Biomass counterfactual scenario and, thus, represent an average regional *BAF* for all current and anticipated expansion in biogenic feedstock consumption from the additional 1 million dry ton feedstock demand shock. All *BAF* equation terms presented in Table L-2 can be replicated based on the cumulative "average" value tables provided in the Supplemental Information section of this appendix, referencing the 2055–2060 simulation period.

Table L-2 presents estimated landscape attributes for each of the three case studies and concludes with two illustrative *BAF* values (with and without default process attributes *P* and *L*, which are assumed to be 1 and 1.1, respectively, for consistency with previous appendices). The third column of the table represents relative growth emissions, or the difference in cumulative forest carbon sequestration between the two scenarios. The fourth column represents relative removal (or harvest) emissions. Note that either of these columns could yield a positive or negative value, depending on the relative difference in these cumulative fluxes between the case study and Zero Biomass baseline scenario. For instance, a positive value in the relative removal column means that forest harvest emissions increase with the additional biogenic feedstock demand in the case study. Relative net growth (in the fifth column) is the sum of relative growth and relative removals. Dividing this absolute emissions change by the regional *PGE* term in the ninth column yields the *GROW* term for the *NBE* equation. Columns six and seven represent relative emissions changes for those fluxes captured by the *SITETNC* term (Table L-1 provides a list of all biogenic carbon-based fluxes included in *AVOIDEMIT* and *SITETNC* for this application).

NBE (eighth column) is the sum of all relative landscape attributes in columns five through seven. In this particular application, *PGE* represents the total *PGE* for the region of assessment. This value represents cumulative additional consumption of biogenic feedstocks for energy generation (in million tCO_2e) for the feedstock scenario over the future time horizon of assessment (2015–2059), and relative to the Zero Biomass case). Thus, this is a regional *PGE* term that could potentially be used to calculate the regional ratios for *GROW, AVOIDEMIT*, and *SITETNC* (depending on the policy program or context).

The final columns represent proof-of-concept *BAF* values for the region and feedstock case study. The first *BAF* value does not adjust for process attributes *P* and *L*. Both the roundwood and logging residue case studies find a long-term cumulative *BAF* value that is very close to 0 or slightly negative in the Southeast roundwood case. The Corn Belt corn stover simulations result in a projected long-term cumulative *BAF* of 0.15, which suggests that 85% of *PGE* released during conversion at a stationary source would be reabsorbed by the landscape.

Table L-2. Illustrative *BAF* Values for the Future Anticipated Baseline Case Studies: Cumulative Average Results from 2015–2060.

		Relative Growth & Removals		*Relative* Carbon Fluxes			*Relative* Total Carbon Flux & Biogenic Emissions			
Scenario	Time Scale	*Relative* Growth Emissions (million tCO_2e)	*Relative* Removals Emissions (million tCO_2e)	*Relative* Net Growth (GROW = Relative growth – relative removals) (million tCO_2e)	*Relative* Avoided Emissions (AVOIDEMIT) (million tCO_2e)	*Relative* Net Landscape Emissions (SITE_TNC) (million tCO_2e)	Net Biogenic Emissions (NBE): Sum of all relative carbon fluxes (million tCO_2e)	Potential Gross Emissions (PGE): All Additional Biogenic Feedstock Consump-tion (million tCO_2e)	Assessment Factor (BAF) (Ratio of relative total carbon flux to relative feedstock flux)	Adjustment Factor (BAF) with Process-Based Equation Terms P and L
SE Roundwood	2015–2060	−37	17	−20	−0.6	−3	−24	672	**−0.03**	**−0.03**
PNW Logging Residues	2015–2060	−14	16	2	0	4	7	155	**0.04**	**0.04**
CB Corn Stover	2015–2060	NA	NA	0	0	16	16	108	**0.15**	**0.16**

5. Case Study Details

5.1. Southeast Roundwood

It is important to consider the regional effects of additional feedstock expansion given regional differences in forest species composition, management techniques, hardwood/softwood mixes, and forest products industry. For example, softwood plantation pine systems are common in the Southeast, and such plantations involve more intensive management but shorter rotations than typical hardwood stands in other regions such as the Northeast. Thus, high levels of emissions from biomass removals could occur more frequently on the landscape in the Southeast, but the carbon payback period could be shorter.

5.1.1. Marginal Effects for the Southeast Roundwood Case Study

Table L-3 displays average periodic and cumulative biogenic CO_2 emissions results for the marginal estimated landscape factor calculations for three separate portions of the simulation horizon (2015–2029, 2015–2044, and 2015–2060).[3] As noted previously, the marginal effect refers to a net change in regional landscape-level emissions and biogenic CO_2 consumption for the feedstock case study relative to the AEO Reference baseline. Estimated per-period landscape factors vary over time for the marginal case, reflecting the cyclical nature of terrestrial CO_2 fluxes from forest management, though this variation is smoothed by averaging over time. Initially, emissions intensity is negative and relatively large in magnitude, reflecting a net increase in carbon

[3] Note that an estimated landscape factor has the same interpretation as the *BAF* without process attribute terms *P* and *L* (presented in Equation 6 of this appendix).

sequestration on the landscape driven by land-owner investment decisions (anticipatory planting) and harvest timing decisions in response to the anticipated long-term demand shift for roundwood-derived biomass. That is, landowners plant new trees and delay harvests in an effort to meet this long-term increase in demand.

Furthermore, the Southeast region is a unique region with historically high levels of observed land use exchanges between agriculture and forestry (Wear and Gries, 2002; Milesi et al., 2003). This phenomenon is evident in the Southeast case study results, as afforestation and pasture-to-cropland transitions occur in response to the added roundwood feedstock requirement leading to periodic fluctuations evident in the *BAF* equation terms and the estimated landscape factor itself. These land use changes can cause large periodic fluctuations in *SITETNC* emissions as new sources of carbon sequestration from afforested stands affect the projected terrestrial carbon balance (as seen in 2035 and 2040). In addition to land use change, differences in forest management techniques and shorter rotations in the Southeast relative to other regions lead to more variability in the *GROW* term as high levels of harvest emissions occur more frequently and forest carbon stocks recover more rapidly.

Table L-3. Southeast Roundwood Landscape Factor Results (Marginal User).

Case Study	Term	Emissions Projection Method	Time Period		
			2015–2030	2015–2045	2015–2060
SE Roundwood Marginal User	------ *additional emissions (t CO_2) from AEO Reference case baseline level* ------				
	GROW	**Per Period**	-478	-444	-587
	SITETNC		-129	-116	-118
	AVOIDEMIT		1.7	1.5	1.3
	PGE		917	1,375	1,528
	Estimated Landscape Factor		-0.66	-0.41	-0.46
	Cumulative additional (t CO_2) from AEO Reference baseline level				
	GROW	**Cumulative**	-6,363	-12,505	-25,610
	SITETNC		-2,920	-4,456	-6,299
	AVOIDEMIT		25	44.7	56.3
	PGE		13,750	41,250	68,750
	Estimated Landscape Factor		-0.67	-0.41	***-0.46***

Cumulative *BAF*s are smoother and less variable overall when compared with the periodic *BAF*s. However, the average of all periodic *BAF* values over the simulation period through 2060 is extremely close to the cumulative landscape factor. Thus, expanded roundwood consumption in the Southeast results in a net reduction in biogenic CO_2 emissions relative to the AEO Reference baseline.

5.1.2. Average Effects for the Southeast Roundwood Case Study

Average effects are displayed in Table L-4. These results include the net change in biomass consumption and emissions for existing levels of consumption, planned expansion, and the additional case study feedstock requirement. Periodic landscape factors are more stable (less variable) under this approach than the marginal effects above, in part because the additional biogenic CO_2 in the denominator includes the biomass consumption already projected to take place. Changes in the denominator are not overwhelmed by the large landscape-level emissions changes present in the numerator. Estimated landscape factors for the "average user" are positive at the beginning of the simulation horizon when the increase in biomass consumption has its greatest effect but decrease over time as landscape biogenic carbon balances recover. Like the "marginal" periodic landscape factors, average periodic landscape factors fluctuate over time and the average by 2060 is less than 0 at −0.07.

Table L-4. Southeast Roundwood Landscape Factor Results (Average User).

Case Study	Term	Emissions Projection Method	Time Period		
			2015–2029	2015–2044	2015–2060
SE Roundwood Average User	*------ additional emissions (t CO_2) from Zero Biomass baseline level ------*				
	GROW	**Per Period**	2,315	138	-769
	SITETNC		651	45	-155
	AVOIDEMIT		-12.3	-9.4	-12.5
	PGE		12,378	13,670	14,069
	Estimated Landscape Factor		0.24	0.01	-0.07
	Cumulative additional emissions (t CO_2) from Zero Biomass baseline level				
	GROW	**Cumulative**	49,031	18,433	-20,308
	SITETNC		13,211	4,802	3,519
	AVOIDEMIT		-228	-325.3	-604.8
	PGE		225,072	449,508	672,489
	Estimated Landscape Factor		0.28	0.05	***-0.03***

Cumulative landscape factors end with a similar total in 2060 to the periodic average (−0.03). Note that this result differs from the previous "marginal" user landscape factor. An "average" value includes the landscape-level emissions effect of all biomass users (current, planned, and the additional roundwood consumption source), whereas the marginal case captures only the change in roundwood consumption (relative to all current and planned sources). The key difference here is that the marginal result is capturing land management changes early in the simulation horizon (afforestation, longer forest rotations) in anticipation of the long-term increase in roundwood demand. Much of the emissions effect of moving from zero biomass consumption to the feedstock case study is captured in the AEO Reference baseline, so the resulting change from AEO Reference to the roundwood feedstock case is only capturing the additional emissions and biomass consumption attributable to the additional roundwood demand source. Figure L-1 compares this case study's cumulative average user trend *BAFs* with the average regional *BAF*s for the AEO Reference case baseline scenario presented in Appendix K (when comparing the AEO Reference case baseline to the Zero Biomass Baseline scenario).

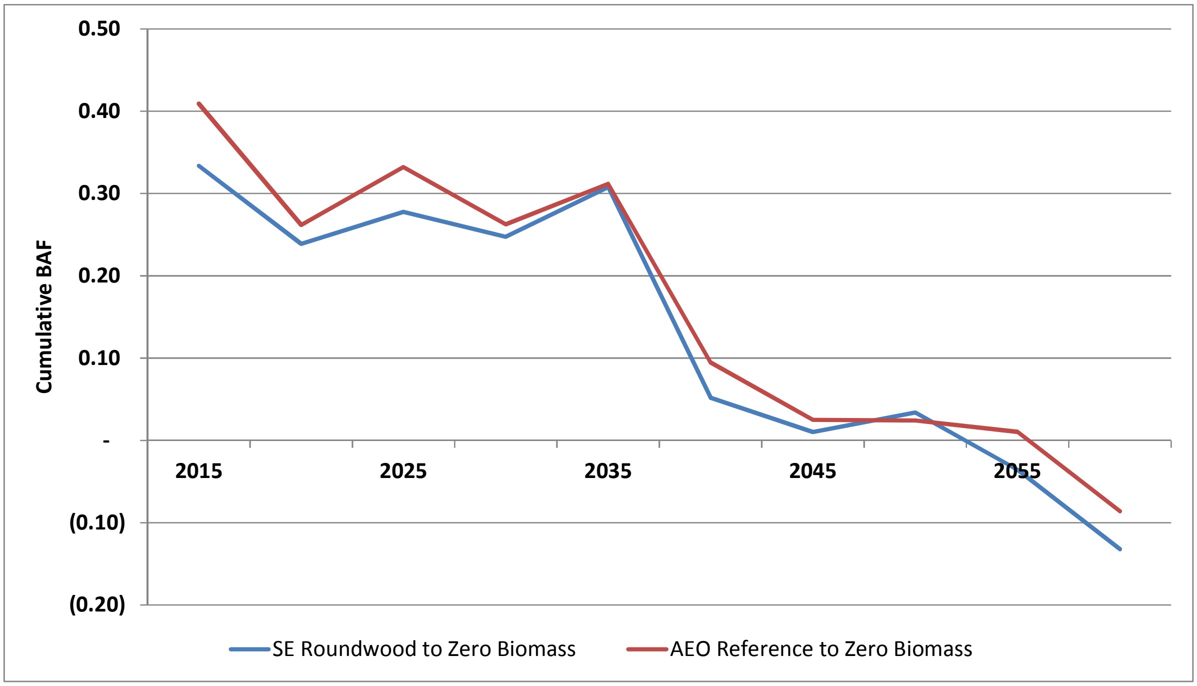

Figure L-1. Comparison of Average Cumulative Landscape Factors in the Southeast Region for the AEO Reference Case Baseline and Roundwood Case Study Relative to the Zero Biomass Scenario.

5.2. Pacific Northwest (PNW) Logging Residues

The PNW logging residues case study simulates a demand for additional feedstock that is met entirely from soft and hardwood logging residues. This case study helps illustrate the potential biogenic CO_2 effects of increased demand for logging residues as a bioenergy feedstock. It is important to note that the FASOM-GHG model divides the PNW into western and eastern regions, reflecting differences in ecological, environmental, and production processes on either side of the Cascade Range in Oregon and Washington. This analysis only includes the western portion of the PNW where cool, relatively dry summers and mild, wet winters yield highly productive Douglas-fir, hemlock, and spruce forests. A full evaluation of the PNW region would require including the eastern portions of Oregon and Washington, which are primarily agricultural regions with limited market interaction with the area included in this assessment.

5.2.1. Marginal Effects for the PNW Logging Residue Case Study

Table L-5 displays landscape factors for the PNW logging residue case study (marginal user case). Unlike the roundwood case studies previously examined, projected marginal *BAFs* are positive at the beginning of the analysis, quickly become negative through the near to medium term, and then become positive toward the end of the simulation horizon. This trend holds for both the periodic and cumulative marginal user calculations. Early in the simulation horizon, the model projects that the additional biomass requirement leads to increased forest harvest emissions. An increase in logging residue demand leads to a net increase in roundwood harvests for other products in order to meet the additional residue demand. Then, afforestation and forest management responses to the feedstock requirement lead to an increase in biogenic carbon sequestration (hence, large negative values for *GROW*), resulting in negative landscape factors from 2020–2040. Over the long term, however, this effect flips as harvest emissions outweigh growth in landscape-level biogenic carbon sequestration.

The large emissions increase in *GROW* leads to high positive values for the periodic landscape factors (greater than 1) and flips the sign for the cumulative landscape factor by 2050. The average periodic landscape factor from 2015–2055 is 0.25, and the cumulative landscape factor in 2055 is slightly higher at 0.3. Thus, relative to the AEO Reference baseline, isolated expansion in logging residue consumption in the PNW would lead to a slight increase in biogenic CO_2 emissions.

Table L-5. PNW Logging Residue Landscape Factor Results (Marginal User).

Case Study	Term	Emissions Projection Method	Time Period		
			2015–2030	2015–2045	2015–2060
PNW Logging Residue Marginal User	------ *additional emissions (t CO_2) from AEO Reference case baseline level* ------				
	GROW	Per Period	-400	-141	261
	SITETNC		-36	96	126
	AVOIDEMIT		1.0	0.3	-0.2
	PGE		917	1,375	1,528
	Estimated Landscape Factor		-0.47	0.03	0.25
	Cumulative additional emissions (t CO_2) from AEO Reference case baseline level				
	GROW	Cumulative	-3,531	-1,748	14,197
	SITETNC		214	3,630	6,408
	AVOIDEMIT		15	8.5	-7.5
	PGE		13,750	41,250	68,750
	Estimated Landscape Factor		-0.24	0.05	***0.30***

5.2.2. Average Effects for the PNW Logging Residue Case Study

For the PNW Logging Residue case, average user landscape factors, or the combined effects of current consumption, planned expansion, and the additional feedstock consumption source, trend toward 0 over time (Table L-6). Net emissions decrease rapidly initially due to additional tree planting and changes in forest management in response to the anticipated feedstock demand. Figure L-2 provides a comparison of cumulative landscape factor values for the AEO Reference and PNW logging residue scenarios, respectively, relative to the Zero Biomass case. The additional logging residue feedstock demand leads to a slight reduction in emissions intensity over the medium term due to anticipatory land management, but a slight increase in emissions over the long term due to sustained harvest emissions that increase with the demand for logging residues. The cumulative landscape factor is close to 0 (0.04) but positive in the 2050–2060 assessment period.

Table L-6. PNW Logging Residue Landscape Factor Results (Average User).

Case Study	Term	Emissions Projection Method	Time Period 2015–2030	Time Period 2015–2045	Time Period 2015–2060
PNW Logging Res Average User	------ *additional emissions (t CO_2) from Zero Biomass baseline level* ------				
	GROW	**Per Period**	-80	-784	-195
	SITETNC		-29	-33	39
	AVOIDEMIT		0.7	0.0	-0.2
	PGE		2,584	3,119	3,301
	Estimated Landscape Factor		-0.04	-0.26	-0.05
	Cumulative additional emissions (t CO_2) from Zero Biomass baseline level				
	GROW	**Cumulative**	9,923	-12,398	2,355
	SITETNC		2,158	1,591	4,358
	AVOIDEMIT		9	-0.4	-8.5
	PGE		45,098	99,893	154,896
	Estimated Landscape Factor		0.27	-0.11	***0.04***

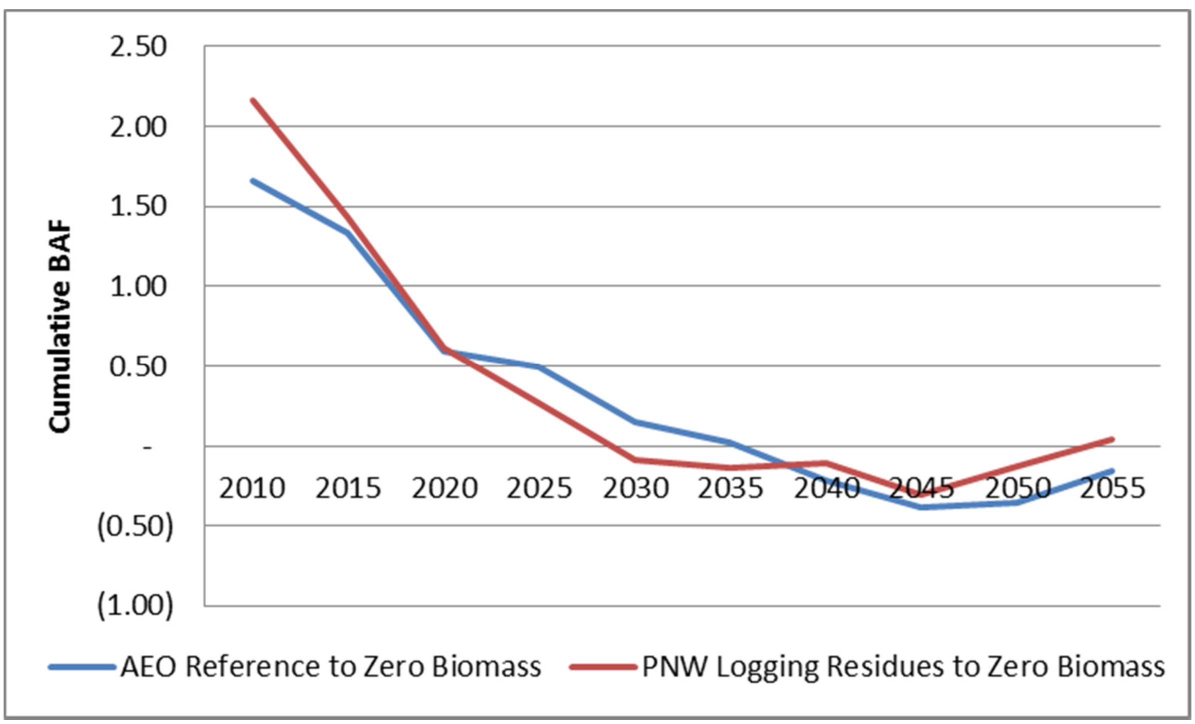

Figure L-2. Comparison of Average Cumulative Landscape Factors in the PNW Region for the AEO Reference Case and PNW Logging Residue Case Study Relative to the Zero Biomass Scenario.

5.3. Corn Belt Corn Stover

The Corn Belt corn stover case study applies the same additional 1 million ton biomass shock over time to the Corn Belt region and requires this additional biomass demand to be met exclusively with corn residues from this region. However, there are some accounting differences between the corn stover case studies and the previous two roundwood scenarios. The *GROW* term defaults to 0 for agricultural biomass sources in this methodology. The assumption is that, with annual crops, biogenic CO_2 "growth" in this context equals what is harvested (removed) from the system for energy generation. However, because this effort seeks to also capture changes in landscape-level emissions, forest tree carbon and harvest emissions changes engendered by the increase in corn stover removal are included in the *SITETNC* term.

One important point regarding the Corn Belt case study is that for each alternative future baseline, a significant amount of corn residue is projected to be harvested in the Corn Belt for producing cellulosic ethanol to meet the RFS2 advanced biofuel mandates (approximately 6.2 billion gallons). Thus, the additional biogenic feedstock constraint will pull from corn stover resources above and beyond what is used to produce cellulosic ethanol.

5.3.1. Marginal Effects for the Corn Belt Corn Stover Case Study

Table L-7 displays marginal *BAF* results for the Corn Belt corn stover case study. Unlike the roundwood scenarios, emissions fluxes are relatively stable over time. For the majority of the simulation horizon, periodic landscape factors are positive (but less than 1), which is driven by increased emissions from *SITETNC* carbon pools on the landscape. After 2015, the proportion of conventional tillage to no-till and conservation till stays relatively constant (thus, there are only minor biogenic soil carbon effects from increased residue harvesting). The majority of *SITETNC* emissions are due to forest harvest fluxes and small levels of deforestation for crop production in response to the additional feedstock demand.

Table L-7. Corn Belt Corn Stover Landscape Factor Results (Marginal User).

Case Study	Term	Emissions Projection Method	Time Period 2015–2030	Time Period 2015–2045	Time Period 2015–2060
CB Corn Stover Marginal User	------ *additional emissions (t CO_2) from AEO Reference case baseline level* ------				
	GROW	Per Period	0	0	0
	SITETNC		183	265	123
	AVOIDEMIT		0.0	0.1	0.0
	PGE		917	1,375	1,528
	Estimated Landscape Factor		0.20	0.19	0.08
	Cumulative additional emissions per ton of additional feedstock usage (t CO_2) from AEO Reference case baseline level				
	GROW	Cumulat ive	0	0	0
	SITETNC		2,645	7,838	5,435
	AVOIDEMIT		0	1.7	2.0

	PGE		13,750	41,250	68,750
	Estimated Landscape Factor		0.19	0.19	***0.08***

Cumulative *BAF* values are also relatively stable over time, ending up at 0.08. Thus, 40 years after the initial corn stover demand shock, only a small portion of biogenic CO_2 emissions from additional corn stover removals are not balanced by landscape biogenic CO_2 sequestration from land management changes.

5.3.2. Average Effects for the Corn Belt Corn Stover Case Study

Although the marginal effects in this case study are relatively stable, average effects fluctuate considerably over time in the Corn Belt region (Table L-8). The overall trend is similar to the alternative baseline Corn Belt regional results presented in Appendix K (AEO Reference relative to Zero Biomass) in that biogenic emissions are highly negative (high level of sequestration) in 2015 and then increase over time (see Figure L-3). However, the additional corn stover requirement increases net biogenic CO_2 emissions (hence the positive periodic flux values in the marginal case), which essentially shifts the *BAF* trajectory up for the majority of the simulation horizon. Note that the two *BAF* trajectories below converge over the long term, indicating a rise in land use change emissions in the AEO Reference baseline in the long term.

In general, these results show that although biogenic CO_2 emissions from corn stover biomass removals in the Corn Belt might be predominately offset by landscape-level CO_2 accumulation, additional expansion of corn stover demand could increase the value of agricultural land relative to other uses, which could drive land use change and increase net emissions (especially if the land is converted to agricultural use from forestry). However, even with the resulting emissions effects, biogenic CO_2 emissions from corn stover consumption in this scenario are almost fully offset by landscape-level CO_2 changes in this case study scenario.

Table L-8. Corn Belt Corn Stover Landscape Factor Results (Average User).

Case Study	Term	Emissions Projection Method	Time Period		
			2015–2030	**2015–2045**	**2015–2060**
CB Corn Stover Average User	------ *additional emissions (t CO_2) from Zero Biomass baseline levels* ------				
	GROW	**Per Period**	0	0	0
	SITETNC		-3,047	-2,064	433
	AVOIDEMIT		-2.4	-2.1	-0.9
	PGE		1,611	2,149	2,337
	Estimated Landscape Factor		-1.89	-0.96	0.81

Case Study	Term	Emissions Projection Method	Time Period		
			2015-2030	2015-2045	2015-2060
	Cumulative additional emissions (t CO_2) from Zero Biomass baseline level				
	GROW	Cumulative	0	0	0
	SITETNC		48,791	-65,015	16,425
	AVOIDEMIT		-37	-64.2	-42.4
	PGE		26,771	67,069	107,770
	Estimated Landscape Factor		-1.82	-0.97	***0.15***

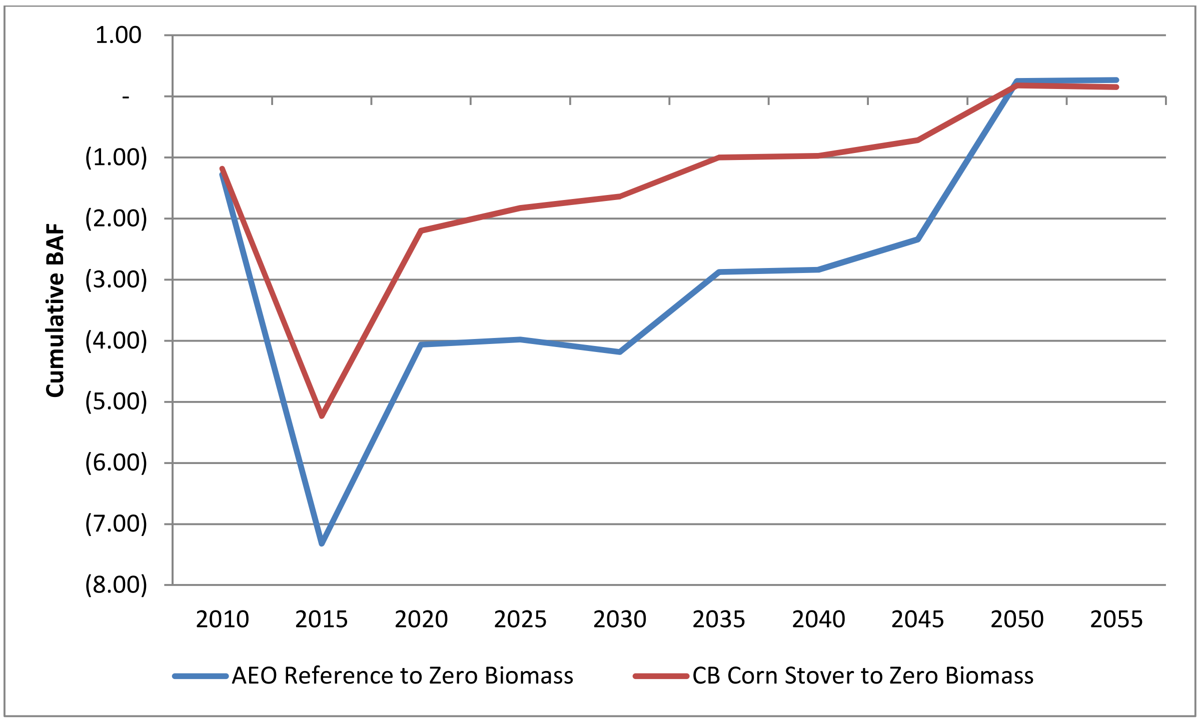

Figure L-3. Comparison of Average Cumulative Landscape Factors in the Corn Belt Region for the AEO Reference Case Baseline and Corn Stover Case Study Relative to the Zero Biomass Scenario.

6. Summary

The illustrative *BAF* values presented in this appendix do not reflect any specific policies or programs; rather they are estimated outcomes based on the baseline and scenario constructs, as well as the assumptions and parameters in the modeling system. The goal of this exercise is to illustrate the functionality of the future anticipated baseline approach and to provide insights into potential effects of biogenic feedstock production and consumption, the possible directionality of results, investor/market behavior, and magnitude of additionality (per the given specific assumptions and modeling system). There are different temporal and spatial scales that could be used, and choices pertaining to these factors can impact results.

Ultimately, the illustrative case studies and estimated values in this appendix are meant to demonstrate the flexibility of the framework as well as the importance of decisions made in terms of how results are to be calculated. Therefore, decisions about time, space, data aggregation, etc., all should be specific to the policy or program to which the framework is applied.

Appendix M provides an overview and discussion of illustrative case study results as well as sensitivities derived from both the retrospective reference point and future anticipated baseline applications. In that appendix, the future anticipated results reflect the comparison of the 1 million ton increased feedstock scenario to the Zero Biomass scenario to provide an estimate of the average biogenic CO_2 emissions effect for all existing and planned biogenic feedstock consumption at national and regional scales and also applies the cumulative calculation method.

7. References

Milesi, C., Elvidge, C. D., Nemani, R. R., & Running, S. W. (2003). Assessing the impact of urban land development on net primary productivity in the southeastern United States. *Remote Sensing of Environment 86*(3):401-410.

Wear, D. N. and Greis, J.G. (2002). The Southern Forest Resource Assessment. http://www.srs.fs.usda.gov/sustain/report/pdf/sfra_summary_e.pdf

8. Supplemental Data and Information

8.1. Details on FASOM-GHG Carbon Accounting

FASOM-GHG incorporates detailed accounting for GHGs emitted from and sequestered by forestry and agricultural activities and land use change in the United States, including the dynamics of carbon sequestration in forests, soils, and wood products. In addition, the model tracks GHG emission reductions in other sectors caused by mitigation actions in the forest and agricultural sectors. In addition to CO_2, FASOM-GHG's accounting also includes CH_4, and N_2O. In this section, we provide additional information on the CO_2 accounting functions and parameters used within the model.

To compare landscape-level emissions across baselines, the following CO_2 flux categories are aggregated to yield a total net emissions flux. This aggregation is calculated for every time step in the simulation horizon (5-year time steps). Then, annual averages are evaluated for different portions in the simulated horizon to highlight the importance of temporal dynamics.

8.1.1. FASOM-GHG Biogenic Feedstock Growth Functions

For FASOM-GHG output, the *GROW* term focuses primarily on forest growth in the context of longer rotation woody biomass (i.e., roundwood). Short rotation woody crops such as hybrid poplar and willow do occur over time frames longer than a year and would typically be produced in plantations (which would achieve a steady state of CO_2 flux; thus, growth would be in balance with removals). The agricultural feedstocks complete an entire growth/harvest/combustion cycle entirely within a year (and thus any CO_2 sequestration in the feedstock would also be balanced by its removal and use). In FASOM-GHG the net forest carbon growth from period to period equated to *GROW* in the *BAF* equation would be best represented with the change in tree carbon over that same time period less any removals. This could be evaluated both regionally and nationally. Note that this net change in tree carbon would include both growth of trees that did not get harvested as well as a loss associated with the trees that did get harvested (removals).

FASOM-GHG tree carbon calculation is based on two primary sources: timber yields and a set of factors that convert those yields to carbon. With the exception of the Pacific Northwest-West (PNWW) region, the timber yields come from the ATLAS model (Mills and Adams, 2007) as used in the national 2005 RPA Assessment Update (Haynes et al., 2007). In the PNWW the yields are based on FIA plots "grown" using the Forest Vegetation Simulator (FVS) and then averaged over strata. The yields include options for partial harvesting regimes of one or more thinning entries only in the PNWW, Southeast (SE), and South central (SC) regions. The conversion of yields for all management regimes including those that involve partial harvests to carbon are based on Smith et al. (2006).

The growing stock volumes (V_A) from the FASOM-GHG yield tables are in thousands of cubic feet per acre and therefore must be converted to cubic meters per hectare (V_H) for use in the carbon equations. The volumes per acre are converted using the following equation:[4]

$$\mathbf{V_H = \frac{1000 \cdot V_A}{14.29}} \qquad \textbf{(EQ. L.7)}$$

To convert these volumes to carbon for the regions and forest types in Smith et al. (2007) were mapped to FASOM-GHG regions, and forest types and weighted averages of the parameters were calculated based on acreages from FIA. In addition to the basic Smith et al. (2007) equations (the 1605b tables), the FASOM-GHG parameters include tree carbon and young stand adjustment from an update by Jim Smith in 2007. The *L1*, *L2*, and *L3* parameters[5] displayed in Table L-9 are for the live tree mass equation, the *D2* and *D3* parameters are for the dead tree mass equation, and the *C1* parameter is used to "ramp up" the mass in young stands (because they may have no growing stock volume).

Table L-9. FASOM-GHG Live and Dead Tree Biomass Equation Parameters.

Region and Forest Type	Carbon Equation Parameters					
	L1	L2	L3	D2	D3	C1
CB						
SOFT	14.434	2.937	0.804	1.754	0.397	8.74
HARD	29.651	2.493	0.861	2.996	0.266	9.89
LS						
SOFT	14.434	2.937	0.804	1.754	0.397	8.74
HARD	29.651	2.493	0.861	2.996	0.266	9.89

[4] Note that this equation is different from the 2008 FASOM-GHG documentation Section 13.2.1.1 where adjustments are made to the growing stock volumes up to total volumes as the model has been updated.
[5] Note that these are the values we use after the weighted average from FIA process. They therefore do not match the 1605b values exactly.

Region and Forest Type		Carbon Equation Parameters					
		L1	L2	L3	D2	D3	C1
NE							
	SOFT	35.372	2.062	0.85	4.056	0.233	9.941
	HARD	31.51	2.598	0.843	3.108	0.266	8.79
RM							
	SOFT	11.082	2.836	0.776	2.543	0.402	9.749
	HARD	11.082	2.836	0.776	2.543	0.402	9.749
PSW							
	SOFT	33.524	2.022	0.852	3.099	0.12	35.277
	HARD	20.852	2.632	0.836	3.211	0.343	9.889
PNWW							
	DOUG_FIR	31.823	1.102	0.949	5.691	0.336	6.1
	OTH_SWDS	17.599	1.822	0.881	1.847	0.554	7.081
	HARD	20.852	2.632	0.836	3.211	0.343	9.889
PNWE							
	SOFT	33.524	2.022	0.852	3.099	0.12	35.277
	HARD	20.852	2.632	0.836	3.211	0.343	9.889

Region and Forest Type	Carbon Equation Parameters					
	L1	L2	L3	D2	D3	C1
SC						
NAT_PINE	37.244	1.553	0.846	1.203	0.271	5.743
OAK_PINE	30.637	2.734	0.798	1.133	0.337	5.986
PLNT_PINE	30.652	1.899	0.815	1	0.138	4.107
SOFT	37.244	1.553	0.846	1.203	0.271	5.743
BOT_HARD	25.128	4.691	0.741	4.056	0.137	7.986
HARD	25.128	4.691	0.741	4.056	0.137	7.986
UP_HARD	46.794	1.964	0.876	2.396	0.186	9.381
SE						
NAT_PINE	34.818	1.242	0.892	1	0.324	4.91
OAK_PINE	21.645	2.626	0.811	1	0.351	4.351
PLNT_PINE	34.148	1.157	0.908	1	0.265	4.8
SOFT	34.818	1.242	0.892	1	0.324	4.91
BOT_HARD	22.811	3.978	0.756	1.747	0.337	5.498
HARD	22.811	3.978	0.756	1.747	0.337	5.498
UP_HARD	28.976	3.213	0.803	2.256	0.257	6.108

Tree carbon is calculated as the sum of live mass (C_{live}):

$$\mathbf{C_{live}} = \left(\mathbf{1} - \mathbf{e}^{\left(\frac{-\mathbf{age}}{\mathbf{C1}}\right)}\right)\left(\mathbf{L1} + \mathbf{L2} \cdot \mathbf{V_H^{L3}}\right) \qquad \textbf{(EQ. L.8)}$$

And dead mass (C_{dead}):

$$\mathbf{C_{dead}} = \left(\mathbf{1} - \mathbf{e}^{\left(\frac{-\mathbf{age}}{\mathbf{C1}}\right)}\right)\left(\mathbf{D2} \cdot \mathbf{V_H^{D3}}\right) \qquad \textbf{(EQ. L.9)}$$

And converted to tree carbon per acre (C_{tree}) based on half of the mass being the carbon content:

$$\mathbf{C_{tree}} = \frac{(\mathbf{C_{live}} + \mathbf{C_{dead}})}{\mathbf{0.5 \cdot 2.471}} \qquad \textbf{(EQ. L.10)}$$

8.1.2. FASOM-GHG Functions Relating to Changes in Site Emissions

The *SITETNC* term represents the feedstock production site-level difference in the net CO_2 flux to the atmosphere when biogenic feedstocks are used for bioenergy compared with a previous use/activity considering both emissions and sequestration changes (e.g., in the case of land use change or residue removal). In FASOM-GHG it may be difficult to differentiate between forest organic soil changes and forest litter and understory changes resulting from harvest residual removal. FASOM-GHG has stable soil carbon estimates for each of the major land use classifications (cropland, pasture, afforestation, and forest). Upon land use change there is a linear transition between the prior soil carbon level and that of the new use. The change in these soil carbon accounts resulting from additional biomass utilization can be evaluated by simply taking the difference between scenarios. The litter and understory carbon is based on a forest floor equation along with estimates of understory and coarse woody debris. Unlike tree carbon, these values adapted from Smith et al. (2007) are based solely on forest age, region, and forest type. The parameters for the equation are provided by Table L-10.

Table L-10. FASOM-GHG Forest Floor Biomass Equation Parameters.

Region and Forest Type		Forest Floor Carbon Parameters					
		A	B	C	D	und	cwd
CB							
	SOFT	42	57.6	23.9	13.9	2.1	13.8
	HARD	44.7	59.5	28.9	13.2	2.4	10.8
LS							
	SOFT	42	57.6	23.9	13.9	2.1	13.8
	HARD	44.7	59.5	28.9	13.2	2.4	10.8
NE							
	SOFT	42	57.6	23.9	13.9	2.6	12.2
	HARD	44.7	59.5	28.9	13.2	2.2	11.2
RM							
	SOFT	42	57.6	23.9	13.9	5.7	12.6
	HARD	44.7	59.5	28.9	13.2	9.2	26.7
PSW							
	SOFT	42	57.6	23.9	13.9	4.9	12.8
	HARD	44.7	59.5	28.9	13.2	2.8	11.5
PNWW							
	DOUG_FIR	87.5	116.7	27.5	16	2	11.9
	OTH_SWDS	87.5	116.7	27.5	16	3.2	15.4
	HARD	44.7	59.5	28.9	13.2	4.5	3.9
PNWE							
	SOFT	87.5	116.7	27.5	16	3	14.8
	HARD	44.7	59.5	28.9	13.2	4.5	3.9
SC							
	NAT_PINE	20.4	27.1	12.2	3.8	5.9	18.6
	OAK_PINE	20.4	27.1	12.2	3.8	4.4	17.3
	PLNT_PINE	20.4	27.1	12.2	3.8	5.9	18.6
	SOFT	20.4	27.1	12.2	3.8	5.9	18.6
	BOT_HARD	15.4	40.9	8.2	3.5	2.2	15.7
	HARD	15.4	40.9	8.2	3.5	2.2	15.7
	UP_HARD	15.4	40.9	8.2	3.5	3.7	15
SE							
	NAT_PINE	20.4	27.1	12.2	3.8	6.8	23.9
	OAK_PINE	20.4	27.1	12.2	3.8	4.4	17.3
	PLNT_PINE	20.4	27.1	12.2	3.8	6.8	23.9
	SOFT	20.4	27.1	12.2	3.8	6.8	23.9
	BOT_HARD	15.4	40.9	8.2	3.5	2.2	21.8
	HARD	15.4	40.9	8.2	3.5	2.2	21.8
	UP_HARD	15.4	40.9	8.2	3.5	4.4	24.3

The litter, understory, and coarse woody debris (U) is then calculated as:

$$\mathbf{U} = \frac{\left(\frac{\mathbf{A \cdot age}}{\mathbf{B+age}}\right) + \mathbf{C \cdot e}^{-\left(\frac{\mathbf{age}}{\mathbf{D}}\right)}}{\mathbf{2.471}} + \frac{\mathbf{(Und+Cwd) \cdot L \cdot 0.5}}{\mathbf{100 \cdot 2.471}} \quad \textbf{(EQ. L.11)}$$

If it is the first rotation (afforestation), the C and D terms are dropped, giving:

$$\mathbf{U} = \frac{\left(\frac{\mathbf{A \cdot age}}{\mathbf{B+age}}\right)}{\mathbf{2.471}} + \frac{\mathbf{(Und+Cwd) \cdot L \cdot 0.5}}{\mathbf{100 \cdot 2.471}} \quad \textbf{(EQ. L.12)}$$

In addition to the litter, understory, and coarse woody debris carbon pools, FASOM-GHG tracks soil carbon. The approach used is adapted from earlier work by Birdsey (1996a), which had fixed forestland carbon values in all regions except the South[6] that varied by region, while Smith et al. (2006) have all carbon in forest soils assumed to be constant over time but varied by region and forest type. Birdsey (1996a) also has soil carbon estimates for land that has been converted from both crop and pasture to forest that rises from an initial value that differs for crop or pasture land to a steady state clos but not equal to, the forestland steady-state soil carbon values. To keep soil carbon values consistent across land use types (crop, pasture, and forest), FASOM-GHG does not use any of the Birdsey (1996a) or Smith et al. (2006) values but rather a loosely based approximation of their values and trends.

To begin, the FASOM-GHG uses century-based crop and pasture soil values that are constant in each region. Table L-11 provides those values.

Table L-11. FASOM-GHG Agricultural Soil Carbon Constants by Land Use and Region.

Region	FASOM-GHG Agricultural Land Use				
	Cropland	Cropland_Pasture	Rangeland	Forest_Pasture	Pasture
CB	15.373	18.751	18.751	18.751	18.751
GP	6.872	11.295	11.295	11.295	11.295
LS	9.946	13.619	13.619	13.619	13.619
NE	7.242	11.649	11.649	11.649	11.649
RM	5.463	7.955	7.955	7.955	7.955
PSW	10.554	15.862	15.862	15.862	15.862
PNWW	14.832	23.029			
PNWE	6.665	9.216	9.216	9.216	9.216
SC	15.415	20.12	20.12	20.12	20.12
SE	2.791	4.828	4.828	4.828	4.828
SW	6.471	11.882	11.882	11.882	11.882

[6] Birdsey (1996a) had minor variation (<10%) in soil carbon for southern forest over the life of a stand.

A regression analysis of the Appendix 3 afforestation soil carbon values (Birdsey, 1996b) as a quadratic function of forest stand age after pasture reversion was estimated, yielding the following functional form:

$$\mathbf{C_{soil} = int + t \cdot age + t2 \cdot age^2} \qquad \textbf{(EQ. L.13)}$$

The parameter estimates are provided in Table L-12 (values in thousand pounds of carbon per acres, not tons).

Table L-12. FASOM-GHG Forest Soil Equation Parameters.

Region	Soil Carbon Parameters		
	int	t	t2
SE	44.964	0.626	−0.00337
SC	44.017	0.61	−0.00322
NE	93.884	1.159	−0.00461
LS	75.803	0.938	−0.00383
CB	48.509	0.586	−0.0023
GP	46.655	0.6	−0.00266
RM	46.655	0.6	−0.00266
PNWW	56.686	0.696	−0.00287
PNWE	56.686	0.696	−0.00287
PSW	56.686	0.696	−0.00287
SW	56.686	0.696	−0.00287

The forest soil constants are determined as the maximum soil carbon value achieved when the FASOM-GHG minimum harvest ages for each region, owner, forest type, site class, and management intensity are used in the C_{soil} equation. The values obtained and used for the regional forest soil constants are provided in Table L-13.

Table L-13. FASOM-GHG Forest Soil Carbon Constant by Region in Metric Tons of Carbon per Acre.

Region	Forest
CB	20.561
LS	30.853
NE	40.044
RM	19.931
PSW	24.912
PNWW	22.994
PNWE	24.031
SC	14.303
SE	14.617

Upon conversion from an agricultural use to forest (afforestation), there is a period of soil adjustment from the prior land use fixed soil amount to the new land use fixed soil amount. The adjustment is based on the parameters from Table L-14 using time since conversion as the age. This yields the following conversion values.

Table L-14. FASOM-GHG Soil Carbon Conversion Rates by Years Since Conversion and Region.

Years Since Land Conversion	Region								
	NE	CB	SC	SE	LS	PSW	PNWW	PNWE	RM
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
10	0.05	0.05	0.04	0.04	0.05	0.05	0.05	0.05	0.05
15	0.09	0.09	0.09	0.09	0.09	0.08	0.09	0.09	0.09
20	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
25	0.22	0.22	0.23	0.23	0.22	0.22	0.22	0.22	0.22
30	0.30	0.31	0.32	0.32	0.31	0.30	0.30	0.30	0.30
35	0.39	0.39	0.40	0.40	0.39	0.39	0.39	0.39	0.39
40	0.47	0.47	0.49	0.49	0.47	0.47	0.47	0.47	0.47
45	0.56	0.56	0.57	0.58	0.56	0.55	0.56	0.56	0.56
50	0.63	0.63	0.66	0.66	0.63	0.63	0.63	0.63	0.63
55	0.70	0.70	0.73	0.73	0.70	0.70	0.70	0.70	0.70
60	0.76	0.76	0.79	0.79	0.76	0.76	0.76	0.76	0.76
65	0.82	0.82	0.85	0.85	0.82	0.81	0.82	0.82	0.82
70	0.86	0.86	0.89	0.89	0.86	0.85	0.86	0.86	0.86
75	0.90	0.90	0.93	0.93	0.90	0.90	0.90	0.90	0.90
80	0.92	0.92	0.96	0.96	0.92	0.92	0.92	0.92	0.92
85	0.95	0.95	0.98	0.98	0.95	0.94	0.95	0.95	0.95
90	0.96	0.96	1.00	1.00	0.96	0.96	0.96	0.96	0.96
95	0.97	0.97	1.00	1.00	0.97	0.97	0.98	0.97	0.97
100	0.98	0.98	1.00	1.00	0.98	0.98	0.98	0.98	0.98

Using the conversion rates from Table L-14 and the fixed soil carbon amounts from Tables L-12 and L-13 the carbon flux (ΔC_{soil}) associated with a land movement from pasture (C^{past}_{soil}) to forest (C^{for}_{soil}) using the soil carbon conversion rate, S_t, in year t would be calculated using the following equation:

$$\Delta C_{soil} = (S_{t-1} - S_t)\left(C^{for}_{soil} - C^{past}_{soil}\right) \qquad \textbf{(EQ. L.14)}$$

8.1.3. FASOM-GHG Functions Relating to Changes in Avoided Emissions

In addition to the litter, understory, and coarse woody debris discussed above, FASOM-GHG also accounts for unused fuelwood and logging residues. These are assumed to be different from the coarse wood debris in that unused fuelwood and logging residues can be either used or left to decompose onsite based on region and forest type. Specific decomposition rates from Turner et al.

(1993) and Turner et al. (1995) are applied. Table L-15 gives the FASOM-GHG coarse woody debris decomposition rates.

Table L-15. FASOM-GHG Annual Coarse Woody Debris Decomposition Rates.

Forest Type	FASOM-GHG Region								
	CB	LS	NE	RM	PSW	PNWW	PNWE	SC	SE
Softwood	0.048	0.048	0.053	0.02	0.023	0.027	0.027	0.057	0.057
Hardwood	0.084	0.084	0.069	0.082	0.082	0.082	0.082	0.082	0.082

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