A. ALTERNATIVE FRAMEWORK BASED ON CARBON STOCKS

Introduction

The following appendix describes the alternative framework being proposed by the SAB. Example cases of how the framework might be used are provided in Appendix C. The goal of this alternative framework is to create a transparent and intuitive system that clearly incorporates the timeframe being used and the system boundary used to solve it. Before describing the calculations the key improvements are described below.

To make the framework transparent and intuitive it is directly based on EPA's own words in the 2014 Framework where the basic question involved in the use of biogenic fuel stocks is posed:

"Is more or less carbon stored in the system over time compared to what would have been stored in the absence of changes in biogenic feedstock use?" (Environmental Protection Agency, 2014, pp. J-6)

We interpret system to mean the terrestrial system and loss of carbon stores from the terrestrial system implies, if conservation of mass is to be observed, that there is an increase of carbon flowing to the atmosphere. To follow the conventions in the 2014 Framework, it is assumed that the atmosphere is the reference point for carbon flows which means that a loss from the terrestrial system is viewed as a positive gain to the atmosphere and therefore adding carbon to the atmosphere is given a positive sign. In contrast, removing carbon from the atmosphere is given a negative sign.

The question posed by EPA could be examined at multiple levels: a stand or plot, a small landscape, or a very large area or region comprised of multiple landscapes. The proposed alternative framework can be applied to each of these, however, following our earlier recommendation we assume that it would be applied to the landscape to regional level. Further, we assume that the carbon stores represent the average landscape or regional value at a given time.

In contrast to the 2014 Framework equation which contains terms such as GROW, AVOIDEMIT, SITETNC, LEAK, P, and L which is a mixture of net fluxes and correction terms (i. e., LEAK, P, and L) the proposed alternative is based on the stores in terrestrial pools such as the live, dead, soil, products, material lost in transport, and waste (i.e., disposed carbon that is generally not deliberately used). These terms are based on what the pools are and not necessarily where the pools came from or where they are going or the processes that might influence them. They are also the pools that are typically inventoried and/or modeled. These pools can be aggregated and rearranged as needed or further subdivided, but regardless will still follow conservation of mass and are subject to mass balance. In addition all the terms would be analogous input-output systems although the actual processes causing input and output change. Finally, these stores terms could potentially capture all the so-called upstream and downstream effects of biogenic feedstock use. However, if there is a policy decision to not include downstream effects on material lost in transport and products, then these stores would be omitted. If the policy decision is to account for these downstream effects, then they would be included. If additional terms are required to account for substitution effects (i.e., displacement of fossil carbon due to biogenic

fuel use) then they can be added. In sum, the "new" terms are flexible, readily understood, transparent, and commonly used in many contexts.

The EPA question implies the comparison of two scenarios: one in which there is an increased use of biogenic feedstocks and one in which there is not (or at least no new additional increased use of these feedstocks). We refer to the scenario in which biogenic feedstock use is increased as the policy scenario and the one without this use as the reference scenario. Note that this does not represent a comparison of stores at the stand level at the start and at the end of a harvest rotation, a relationship that is often used to illustrate the "effects" of biofuel harvest. It is often assumed that if the carbon stores at the start of the harvest rotation is regained at the end of the rotation that there is no effect of biogenic carbon harvest on terrestrial carbon stores because the system is in a steady-state over time. This stand level "internal" comparison is irrelevant in the newly proposed framework because it is entirely possible for the reference and the policy scenarios to both eventually be in a steady-state condition, but to have different carbon stores (see Appendix C for three examples).

The proposed framework would specify the system boundaries used to make the calculations, for example whether it included "direct" biophysical or "indirect" market effects or was expanded to include atmospheric effects. Note that by system boundaries, we are not referring to the geographical boundary of the system. Instead, we are referring to the sets of processes that are considered to be inside versus outside the system. The 2014 Framework mixed this concept of system boundaries and net fluxes (i.e., emissions) by the inclusion of the LEAK term. The conceptual problem introduced by the mixing of system boundaries and net fluxes is that whether or not market effects are included in the analysis, the pools and processes controlling these processes remain the same. Understanding the additional amount caused by the inclusion of market effects in the current framework means one has to separate that part of the pool or net flux that was influenced by market effects versus the part that was not. This would prove extremely difficult in practice. In contrast, if one changes the system boundaries to include or exclude market effects, then one can make inferences about the impacts market effects have on each of the pools and their net fluxes.

Finally, the proposed alternative framework uses new terminology to describe the multiple timeframes that could be used to solve the equations. The 2014 Framework proposed three timeframes: 1) per period, the change in the net emissions at any time; 2) cumulative emissions-based, the total amount up to a time point; and 3) average per period-based which was the average over a time period. These terms are ambiguous, for example there are various levels that emissions could be cumulative; and non-intuitive because it mixes the aspect of time being considered (i.e., a time point versus a time period) and the way the data is being treated (i.e., differenced, summed, or averaged). We propose to use subscripts to indicate the timeframe being used and how the primary information (which for NBE (net biogenic emissions) is the difference in stores between the reference and policy scenarios) is being treated:

To represent the value at any time point the subscript t is used. This is verbally referred to as "little" t. If the BAF (biogenic assessment factor) is determined at time point t, then it uses the NBE and PGE (potential gross emissions) at time t. This would the same as the EPA's cumulative emissions-based concept.

Time zero is defined as the time point when the policy has been started (i.e., t=0).

To indicate the time point at which the effects of the biogenic harvest ceases to change, the letter T is used. This is verbally referred to as "big" t. If T is used as a subscript it indicates values at time point T. If the BAF (biogenic assessment factor) is determined at time point T, then it uses the NBE and PGE at time point T.
To represent the rate of change at a particular time (i.e., the marginal rate of change or what the 2014 Framework referred to as the per period value) the subscript Δt is used to signify the change between two times (e.g., t1 and t2). If the time being considered is T, the time when the effects of the biogenic harvest ceases to increase, then the subscript is ΔT, which by definition would be zero mass difference per area per time.

To indicate the sum of the values over a time interval 0 to t years the subscript Σt is used and the subscript ΣT is used it indicates the sum of values over the interval from time 0 to T. This timeframe was not included in the 2014 Framework, but we believe it should be considered as it reflects the long-term effect of all the net carbon fluxes to and from the atmosphere caused by biogenic carbon harvest.

BAF is dimensionless regardless of the timeframe being used. For either the t or the Σt timeframe the units would be difference in stores per area for NBE and cumulative emissions per area for PGE. The units of Δt terms would be in stores difference per area per time.

In addition to clarifying the concepts concerning time, the new terminology makes the relationship of the processes used in treating the data mathematically clearer. If one starts at the t level, then going to the Δt level is analogous to solving the differential at time t. Conversely going to the Σt level from t is analogous to solving the integral over time period 0 to t. One also goes from the Δt to the t level by "integration" and the Σt to the t level by solving the "differential". Hence all the terms become clearly related to one another in the new system.

The NBE, PGE and BAF Equations

The generic formula for calculating BAF (biogenic assessment factor) from NBE (net biogenic emissions) and PGE (potential gross emissions) is the same as in the 2014 Framework regardless of the system boundaries and timeframe used:

$BAF_x = NBE_x / PGE_x$

To keep the versions separate requires that the timeframe and system boundaries be indicated by a subscript (indicated in this case by x). All are ultimately derived from the differences in carbon stores between the reference and policy case. The following sections describe the equations for each timeframe, how they are used and how they relate to one another starting with the version for a time point.

Equations using the t (any point in time) timeframe

The timeframe most closely related to the differences in carbon stores between the reference and the policy scenario uses t. If the BAF is calculated for any point in time (t) for system boundary B the BAF equation is:

$$BAF_{Bt}=NBE_{Bt}/PGE_{Bt}$$

Where NBE_{Bt} and PGE_{Bt} represent the carbon stores difference at time t and the cumulative potential gross emissions up to time t, respectively. The difference in carbon stores between the reference and policy scenarios at time t represents the cumulative net biogenic emissions up to time t and is therefore equivalent to cumulative net biogenic emissions-based concept presented in the 2014 Framework. The sum of potential gross emissions using the t timeframe is:

$$PGE_{Bt} = \sum_{t=0}^{t} PGE_{\Delta t}$$

Where $PGE_{\Delta t}$ is the annual release of carbon related to biogenic carbon combustion for energy or heat.

NBE_t is based on the difference in carbon stores between the reference scenario and the policy scenario at time t. At the most aggregated level the NBE formula for time t and boundary condition B would be:

$$NBE_{Bt}=TC_{reference\ t} - TC_{policy\ t}$$

Where TC stands for terrestrial carbon and NBE_{Bt} represents the difference in carbon stores between reference scenario (reference) and the policy scenario (policy) at time t. The reason the policy scenario is subtracted from reference scenario is to provide the correct sign: a loss of carbon stores caused by the policy scenario would lead to an addition to the atmosphere and hence is given a positive NBE. Conversely a gain in carbon stores caused by the policy scenario would lead to a loss from the atmosphere and hence is given a negative NBE.

If the terrestrial carbon is subdivided then:

$$NBE_{Bt}= (CL_{reference\ t}- CL_{policy\ t}) + (CD_{reference\ t}- CD_{policy\ t}) + (CS_{reference\ t}- CS_{policy\ t}) + (CP_{reference\ t}- CP_{policy\ t}) + (CW_{reference\ t}- CW_{policy\ t}) + (TL_{reference\ t}- TL_{policy\ t})$$

where carbon is tracked as separate live (CL), dead (CD), soil (CS), products (CP), waste pools (CW), and transportation loss (TL) stores.
If the BAF is solved at time T, the point at which the difference between the reference and policy scenario ceases to grow, then the equations are the same but the subscript used changes to T.

Equations using the Δt (change at any point in time) timeframe

As noted above the annual release of carbon related to biogenic carbon combustion for energy or heat is defined as $PGE_{\Delta t}$. This term can be summed to represent the cumulative PGE up to time t (i.e., PGE_t).

To determine T it is necessary to determine when the difference in carbon stores between the reference and policy scenario ceases to change. This is best done by calculating the annual rate at which the difference in scenarios is changing analogous to determining the derivative of the carbon stores

difference. When this rate of increase in the difference is equal to zero (or for practical purposes approaches zero), then the "full" effects of the policy must have become evident and time T has been reached. The rate of change (Δ) in the difference in carbon stores between the reference scenario and the policy scenario at time t for a given system boundary B can be computed as:

$$NBE_{B\Delta t} = \Delta(TC_{reference\ t} - TC_{policy\ t})$$

Expanded out, assuming a time step of one year it would be:

$$\Delta(TC_{reference\ t} - TC_{policy\ t}) = (TC_{reference\ t} - TC_{policy\ t}) - (TC_{reference\ t-1} - TC_{policy\ t-1})$$

which is the change in the carbon stores difference between scenarios between time t and t-1. If a time step other than one year, for example 5 years, is used then it would be the rate of change over that interval (e.g., Δ/5 years) instead.

The annual change (i.e., Δt) equation can be converted to the NBE at time t for boundary condition B as follows:

$$NBE_{Bt} = \sum_{t=0}^{t} \Delta(TC_{reference\ t} - TC_{policy\ t}) = \sum_{t=0}^{t} NBE_{B\Delta t}$$

which is the sum of the annual change in difference in the terrestrial carbon stores between the reference scenario and the policy scenario from year zero to year t.

If terrestrial carbon been subdivided into major stores of carbon (e.g., stores of live (CL), dead (CD), soil (CS), products (CP), waste pools (CW), and transportation loss (TL) pools) it can be summed into an overall rate of change using:

$$NBE_{B\Delta t} = \sum_{t=0}^{t} \Delta(CLrt - CLpt) + \sum_{t=0}^{t} \Delta(CDrt - CDpt) + \sum_{t=0}^{t} \Delta(CSrt - CSpt) + \sum_{t=0}^{t} \Delta(CPrt - CPpt) + \sum_{t=0}^{t} \Delta(CWrt - CWpt) + \sum_{t=0}^{t} \Delta(TLrt - TLpt)$$

Where r indicates the reference and p the policy scenarios.

To "integrate" the subdivided stores to the t timeframe and terrestrial stores level, then the following equation can be used:

$$NBE_{Bt} = \sum_{t=0}^{t} \Delta((CLrt + CDrt + CSrt + CPrt + CWrt + TLrt) - (CLpt + CDpt + CSpt + CPpt + CWpt + TLpt))$$

Other variations of the equations are possible, but the point is that these sets of formulae can be subdivided or aggregated and moved between timeframes readily.

The BAF for this annualized change (Δt) timeframe for a given system boundary B is:

$$BAF_{B\Delta t} = NBE_{B\Delta t} / PGE_{B\Delta t}$$

This version of the BAF is useful to examine the time course of how potential gross emissions and the differences in carbon stores between the two scenarios relate to one another. Typically the magnitude of $BAF_{B\Delta t}$ is highest immediately following implementation of the policy and when T is reached $BAF_{B\Delta t}$ equals zero whether or not the policy causes a carbon gain or a carbon loss relative to the reference scenario. On its own, $BAF_{B\Delta t}$ fails to represent the long-term effect of biogenic carbon use.

It is possible to scale $BAF_{B\Delta t}$ to BAF_t by assuming that the $PGE_{B\Delta t}$ is constant. Although this is not precisely true, examination of the cases in Appendix B indicates that it is a good first approximation of the temporal pattern of $PGE_{B\Delta t}$. Further, $PGE_{\Delta t}$ can be assumed to be equal to 1.

Since $BAF_{\Delta t}$ is the ratio of the $NBE_{\Delta t}$ and $PGE_{\Delta t}$ terms and the latter has a value of 1, one can derive the $NBE_{\Delta t}$ term from $BAF_{\Delta t}$ as follows:

$$BAF_{\Delta t} = NBE_{\Delta t} / PGE_{\Delta t}$$

which since $PGE_{\Delta t}$ is assumed to be 1 is:

$$NBE_{\Delta t} = BAF_{\Delta t}$$

The final equation approximating BAF_t is therefore:

$$BAF_t \approx \sum_{t=0}^{t} BAF_{\Delta t} / t$$

This means that $BAF_{B\Delta t}$ can be scaled to BAF_t using a moving or running average of $BAF_{B\Delta t}$ from time 0 to time t. This is equivalent to EPA's proposed average per time period BAF.

Equations using the Σt (sum over time period) timeframe

An additional timeframe not considered in the 2014 Framework is to consider the sum of the stores differences and potential gross emissions over a time period as opposed to a single point in time. This is signified by the Σt subscript. The BAF using this timeframe for system boundaries B is:

$$BAF_{B\Sigma t} = NBE_{B\Sigma t} / PGE_{B\Sigma t}$$

Where

$$NBE_{B\Sigma t} = \sum_{t=0}^{t} NBE_{Bt}$$

And

$$PGE_{B\Sigma t} = \sum_{t=0}^{t} PGE_{Bt}$$

or alternatively the area under the NBE_{Bt} and PGE_{Bt} curves.

It is possible to scale BAF_t to $BAF_{\Sigma t}$ by assuming that the PGE_t is constant. Although this is not precisely true, examination of the cases in Appendix B indicates that it is a good first approximation of

the temporal pattern of PGE_t. Further, $PGE_{\Delta t}$ can be assumed to be equal to 1 and PGE_t is therefore equal to t.

Since BAF_t is the ratio of the sum of the NBE_t and PGE_t terms and the latter is the time t, one can derive the NBE_t term from BAF_t as follows:

$BAF_t = NBE_t / PGE_t$

which can be rearranged as:

$NBE_t = BAF_t * PGE_t$

or since PGE_t can be represented by time t:

$NBE_t = BAF_t * t$

The final equation approximating $BAF_{\Sigma t}$ is therefore:

$BAF_{\Sigma t} \approx \sum_{t=0}^{t} BAF_t * t / \sum_{t=0}^{t} t$

The rational for computing $BAF_{B\Sigma t}$: Residence time

$BAF_{B\Sigma t}$ is a modification to the Biogenic Accounting Factor (BAF) formula that represents a significant departure from any of EPA's approaches. Given that a ton of carbon contributes to radiative forcing every year it resides in the atmosphere, this modified $BAF_{B\Sigma t}$ takes account of "residence time" of CO2 emissions, i.e. the length of time emissions are resident in the atmosphere. To take account of residence time, our proposed $BAF_{B\Sigma t}$ would accumulate the annual differences in carbon stocks on the land over the entire time horizon. By contrast, EPA's approach to a cumulative BAF would simply account for the difference in carbon *stocks at a single point in time*. By cumulating annual differences across the entire projection period, our proposed $BAF_{B\Sigma t}$ would yield something like the notion of "ton-years" to account for differences in carbon stocks each year. It can also be thought of as a "total, cumulative" BAF. By taking the time path and residence times of emissions into account, we are suggesting a measure that provides a more plausible indicator of the contribution of biogenic emissions to radiative forcing or the overall balance between incoming solar radiation and energy radiated back to space.

Another way to explain the rationale for computing $BAF_{B\Sigma t}$ is that it represents the *average effect* of harvesting a ton of biogenic fuel stock over the entire time period t. After cumulating all the differences in carbon stock, the resulting sum is divided by T. This is opposed to EPA's approach of taking the effect of harvesting carbon at time t (i.e., what is represented by BAF_{Bt}). While $BAF_{B\Delta t}$ can be approximately scaled to BAF_{Bt}, by computing a running average, this methodology does not work particularly well when scaling BAF_{Bt} to $BAF_{B\Sigma t}$.

See Appendix B for a graphical comparison between EPA's cumulative BAF_t and a proposed "total, cumulative" $BAF_{B\Sigma t}$.

Analytical solutions to NBE equations.

While simulation models could be used to estimate the temporal changes in NBE_{BT}, the fact that the formulation is based on pools that have inputs and outputs has major advantages and would allow one to intuitively check the sign and magnitude of NBE_{BT} without elaborate modeling particularly in the case that the reference and policy scenarios eventually reach a steady-state.

Under steady-state conditions the input (I) and output (O) of carbon is equal:

$$I=O$$

Where both I and O have units of mass per area per time. The output is determined by the proportion being lost per unit time (k) and the amount stored when the system is in steady-state (TCss):

$$O= k\ TC_T$$

Where TCss has units of mass per area. Therefore the steady-state can be predicted as:

$$TC_T= I/k$$

This simple formulation applies to all the pools storing carbon (and the virtual stores related to substitutions if that is added) and can be used to test whether the reference scenario or the policy scenario will store more carbon. In the case of increased harvest intensity or frequency k must increase by n and since:

$$TC_{reference\ T} = I/k > TC_{policy\ T} = I/(k(1+n))$$

then NBE_T must be positive if the policy scenario involves an increase in harvest. Conversely, if the policy scenario also includes an increase in I equal to n then it is possible for there to be no loss in carbon because:

$$TC_{reference\ T} = I/k = TC_{policy\ T} = I(1+n)/(k(1+n))$$

In the case in which I and k do not change, for example when the losses in two cases are equivalent (e.g., burning in a power plant versus burning in the field), then there is also no new net loss of carbon.

$$TC_{reference\ T} = I/k = TC_{policy\ T} = I/k$$

Finally, when there is just an increase in I then there is a gain of carbon in the system since:

$$TC_{reference\ T} = I/k < TC_{policy\ T} = I(1+n)/k$$

This might reflect the case of negative leakage in which new forest area is increased and effectively increases I. Examples of how these calculations can be used is illustrated in Appendix B.

System Boundaries

The alternative framework equations could be used for several sets of systems boundaries:

Direct biophysical effects (DB) which would consider the direct effects of harvest on the area harvested for biofuels within a region.

Indirect effects mediated through market signals (IM) which considers responses outside the areas not directly harvested for biofuels. Using this boundary condition would essentially deal with the leakage question without confounding pools or emissions with system boundaries.

Atmospheric responses (AR) in which the temporal effects on greenhouse gas warming of the atmosphere of net carbon added or removed by biofuels activity would be considered.

Full life cycle (LC) in which the effects of substitution for fossil fuels would be considered. While this might be handled by including a substitution pool, it would be specified in the NBE and BAF terms as a change in the system boundary.

Subdividing Terrestrial Carbon Stores

Although one could consider all terrestrial carbon pools in aggregation, the different controls and timing of subpools suggests that it may be better to treat each separately. To address the pools in the original framework the following carbon pools (or something like these) would be needed: live (CL), dead (CD), soil (CS), products (CP), waste pools (CW), and transportation loss (TL) pools. The leakage term would not be needed because it is addressed by changing the system boundaries. This would avoid the current confounding of pools and system boundaries (i.e., the LEAK term influences the live, dead, soil, products, waste, and loss stores; it not a separate kind of store or flux as indicated in the 2014 Framework).

The inclusion of product stores is necessary because the current framework treats all products as having the same infinite life-span, a scientifically unjustifiable assumption. The decision to not include product life-spans appears to be related to a concern that power plants using biogenic carbon should not be responsible for the actions of those creating products because this is an indirect effect. However, leakage is also an indirect effect and is being considered; if indirect effects are considered, then all indirect effects should be considered: the boundary conditions should be consistent once specified. It is not clear that the use of fate of products is beyond the control of the power plant in that the power plant can select to what product the carbon is sent. By not discriminating among products, a long lasting product (e.g., biochar) will have same consequences as a short lasting product. The current framework also ignores the potential effects of biogenic carbon harvest on past accumulations of product stores. to begin with. Neither seems likely. If harvest is diverted into biofuel feedstocks, then the size of the products carbon store accumulated from past harvests would have to decrease, leading to a net flow of carbon to the atmosphere. However, the current framework cannot detect such a flow.

The inclusion of transportation losses as a pool would address another problem with the current framework which assumes that all losses are instantaneous. This simplifying assumption has no basis in science and inflates the PGE term, but does not address the stores. By tracking the changes in this pool, the NBE equation would be more consistent.

While most of the pools can be dealt with on a carbon dioxide basis, the waste pool (i.e., carbon that is disposed of and not deliberately used) involves the release of methane. This is problematical in that methane has a higher greenhouse gas warming potential than carbon dioxide. This could be dealt with in several ways. Waste carbon that is subject to loss via methane could be tracked separately from waste carbon that is lost as carbon dioxide. For example, wood waste carbon is generally not subject to loss via methane, whereas non-woody waste (e.g., garbage) is likely to produce methane during anaerobic decomposition. The stores of these two waste pools could be adjusted to reflect difference in stores in terms of greenhouse gas warming. An alternative would be solve the waste carbon contribution not as a change in stores, but as a change in fluxes. However, this would also require separating waste into the portion generating carbon dioxide versus methane and would introduce non-analogous terms into the NBE formula.

B. A GRAPHICAL COMPARISON BETWEEN EPA'S CUMULATIVE BAF_T AND A PROPOSED "TOTAL, CUMULATIVE" $BAF_{B\Sigma T}$

This appendix provides a series of graphs to allow a visual comparison of the SAB's proposed $BAF_{B\Sigma t}$ to EPA's BAF_T. As shown in Figure 1, the SAB is proposing a measure of $NBE_{\Sigma t}$ that includes the shaded area between the average landscape carbon stores for the policy scenario vis-à-vis the reference scenario. By contrast, EPA's concept of NBEt is shown as the vertical distance between these two lines, meaning they looked at the cumulative difference *only at time t*. Our proposed $NBE_{\Sigma t}$ is again shown in Figure 2 as the shaded area under the orange line which represents the cumulative difference in stores. Figure 4 plots out the $NBE_{\Delta t}$ and $PGE_{\Delta t}$ curves to indicate the timing of emissions and identify T, the time when the policy effect is completed. Summing the values under each of these curves results in Figure 5 which dramatically shows the difference between carbon stores *over a period of time (ΣT)* versus *at a point in time (T)*.

Since we are proposing a ΣT measure that is "cumulative" and EPA also has a measure they are calling "cumulative," we need a way to distinguish them and the versions of BAF stemming from them, hence the different subscripts. EPA's "cumulative" BAF is at *a point in time*. In the case shown in Figure 5 for time T, EPA's BAF_T is calculated by dividing the distance B on the upper graph by distance D on the lower graph (i.e., BAF_T = B/D or $BAF_T = NBE_T/PGE_T$). This results in a value of 0.211. While this represents the net effects *at time T*, it does not represent the total net effects *over time period T*. To estimate these long-term average effects on what might be considered on a ton-year basis, we propose using the areas under the NBEt and PGEt curves as represented by areas A on the upper graph and C on the lower graph to determine the BAF (i.e., $BAF_{\Sigma T}$= A/C or $BAF_{\Sigma T} = NBE_{\Sigma T}/PGE_{\Sigma T}$). This results in a value of 0.334, which reflects the fact that the policy released most of the carbon long before T is reached.

For each figure below, a lengthy explanation of how the terms are used and what they represent is provided.

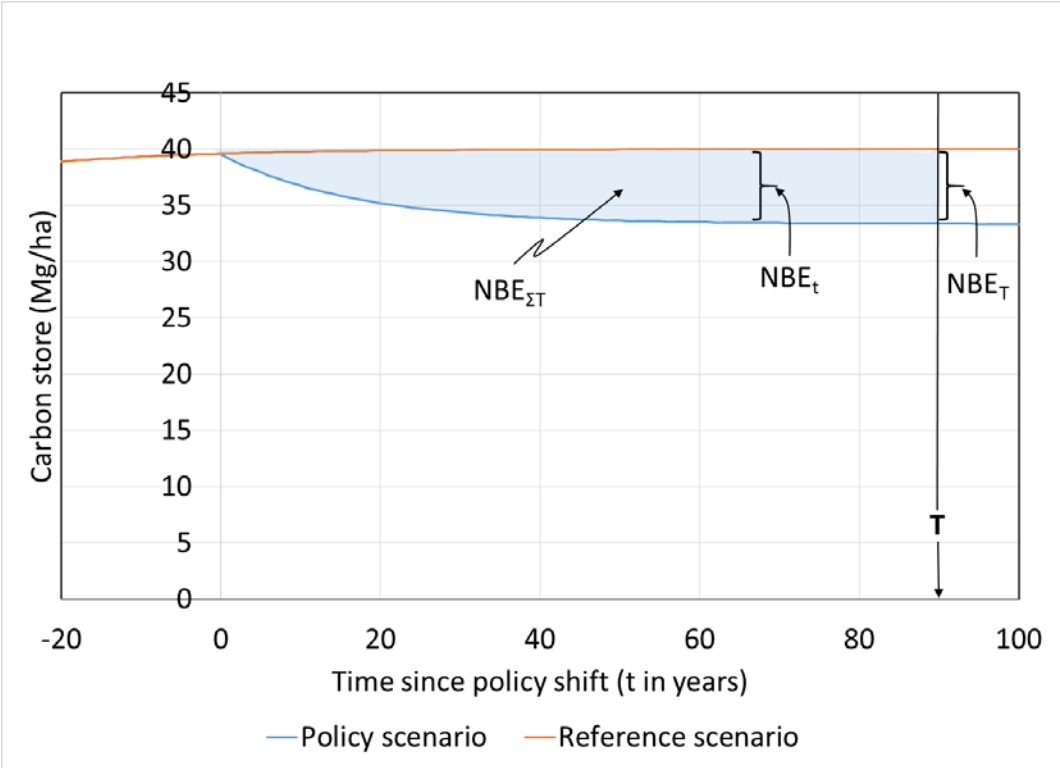

Figure B-1. A graphical illustration of the terms used in the proposed new framework as illustrated using Case 1: Decreasing carbon described in Appendix C. The average landscape carbon stores for the policy (which includes additional biofuel-related harvests) and the reference scenario are represented over time by the blue and orange lines, respectively. The difference between these two scenarios at any time t (i.e., little t) is indicated by the distance between the scenarios indicated by NBE_t. The time when the difference in the carbon stores between the two scenarios ceases to increase is indicated by T (i.e.,big T). The difference between these two scenarios at time T is indicated by NBE_T. For a fuller examination of Case 1 see Appendix C.

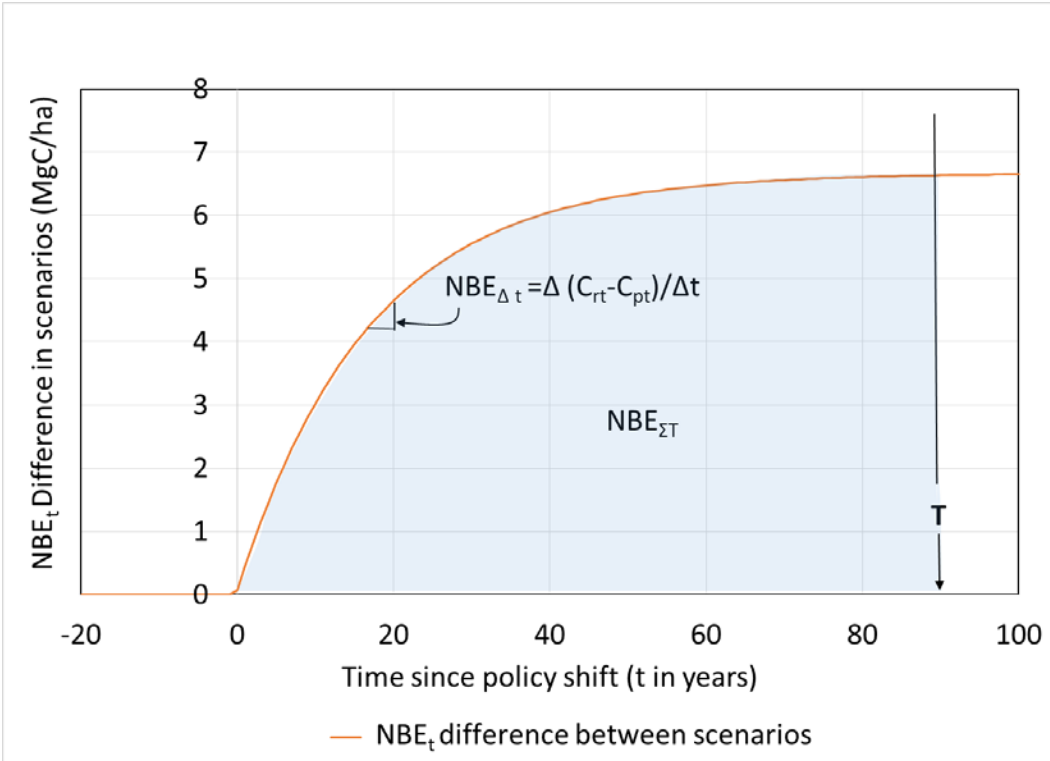

Figure B-2. The carbon stores differences (NBE_t) between the policy and reference scenarios as a function of time t. This difference is represented by the orange line and can be thought of as the cumulative emission to the atmosphere caused by the policy. That is because conservation of mass suggests that if the carbon is not stored in the landscape, it has been released to the atmosphere. Therefore the difference in stores between the two scenarios is caused by emission to the atmosphere. Since the atmosphere is the reference point a loss of carbon caused by the policy is assigned a positive value (as in this case); whereas a gain of carbon in the landscape would be assigned a negative value (see Case 2 in Appendix C). The rate at which this difference is growing each year is represented by $NBE_{\Delta t}$ which might be thought of as the marginal rate of change of the stores differences. The sum of all the differences up to time T (the time the differences in carbon stores ceases to grow) is represented by the shaded area and is termed $NBE_{\Sigma T}$ (i.e, the sum of NBE_t up to time T) and is sometimes called the "wedge".

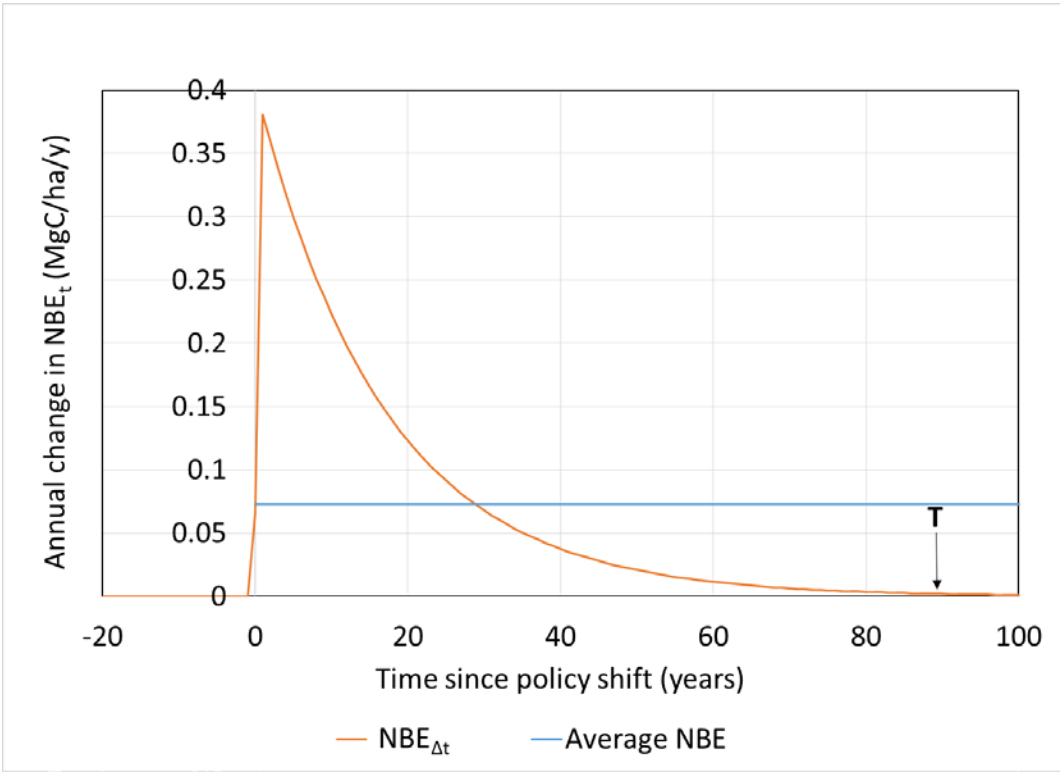

Figure B-3. The annual change in NBE_t is called $NBE_{\Delta t}$ and is depicted by the orange line. As the policy is implemented $NBE_{\Delta t}$ steeply rises but gradually falls off approaching zero by year 90. This indicates that full effects of the policy have been realized by this time which is represented by T (i.e., big T). The blue line represents arithmetic average NBE and is calculated by dividing the difference in stores between the two scenarios at time T by T (i.e., NBE_T/T). For this example, the average does not adequately portray the time course that carbon is being added to the atmosphere. In contrast, $NBE_{\Delta t}$ indicates the largest additions to the atmosphere occur immediately after the policy is implemented and the additions largely cease after time T.

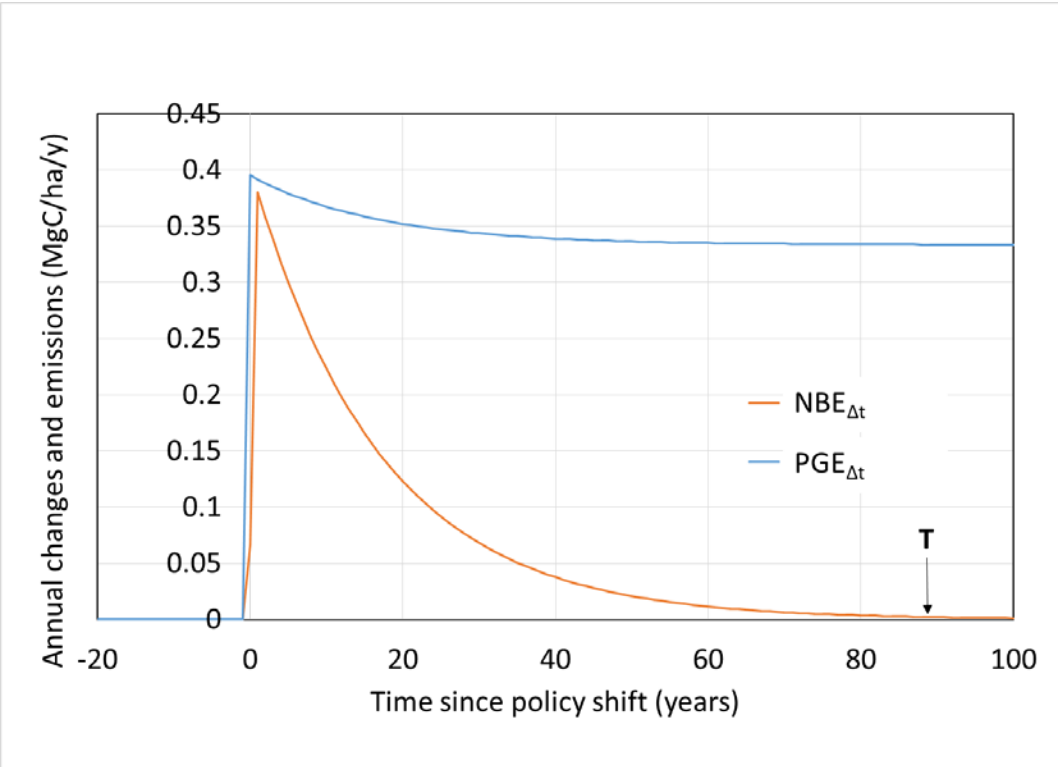

Figure B-4. The various BAF's are calculated by dividing the Net Biogenic Emissions (NBE) by the Potential Gross Emissions (PGE) associated with burning biogenic carbon for energy. In this figure the annual changes in both are considered and are represented by the $NBE_{\Delta t}$ and $PGE_{\Delta t}$ lines (the orange and blue, respectively). One can see that if the BAF is calculated at 5 years it is considerably higher ($BAF_{\Delta t}$ =0.79) than if it is calculated at 90 years (0.005). Examining BAF using this timeframe does not reflect the overall effect of the policy over time period T, the value of which lies somewhere between these extremes. The utility of examining NBE and PGE using the Δt timeframe is that it indicates the timing of the emissions (or uptake) and can be used to identify T, the time when the policy effect is completed. Summing the values under each of these curves results in the curves depicted in Figure 5.

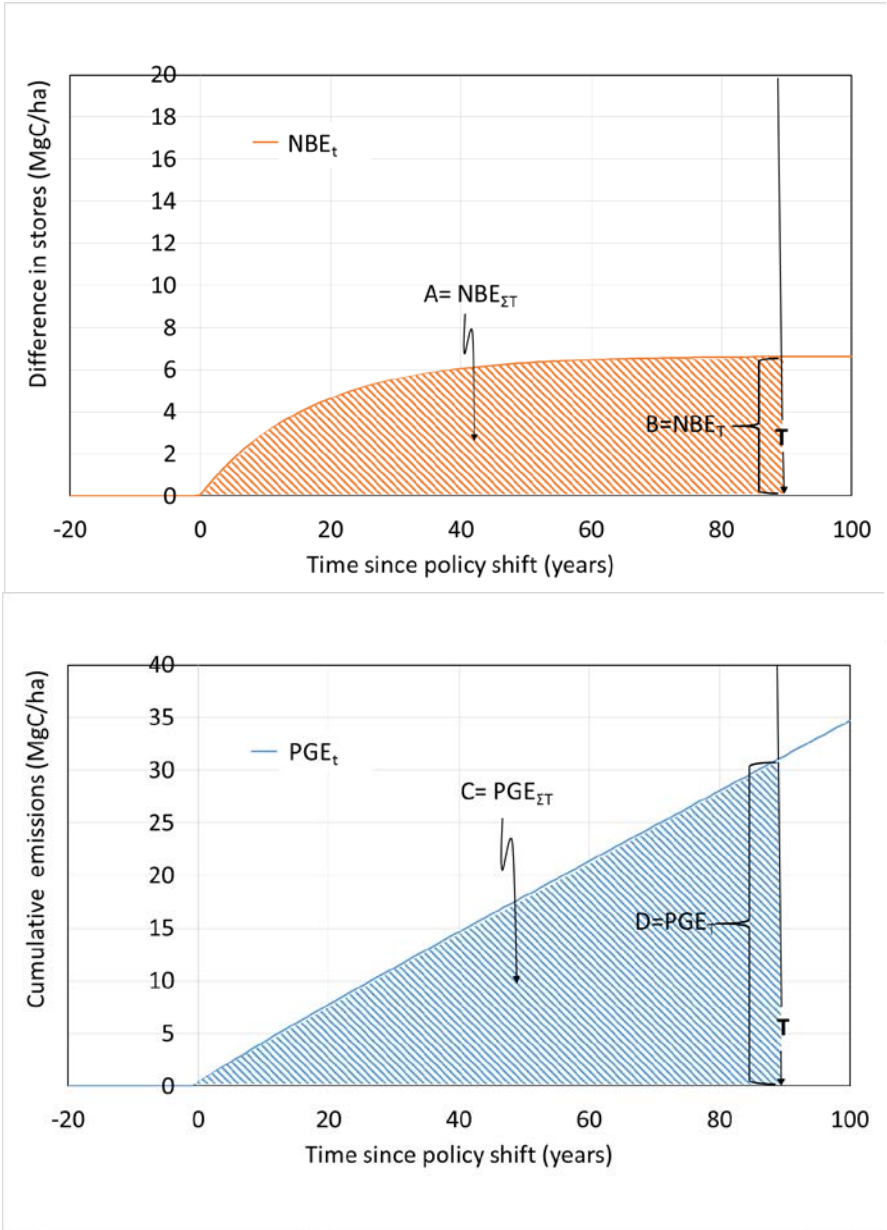

Figure B-5. The cumulative effects of a policy can be represented in two ways: at a point in time (T) or over a period of time (ΣT). Since both are "cumulative" we need a way to distinguish them and the versions of BAF stemming from them, hence the different subscripts. If the timeframe being used is at a point in time, in this case time T, then the BAF is calculated by dividing the distance B on the upper graph by distance D on the lower graph (i.e., $BAF_T = B/D$ or $BAF_T = NBE_T/PGE_T$). This results in a value of 0.211 and while this represents the net effects at time T, it does not represent the net effects over time period T. To estimate these long-term average effects on what might be considered on a ton-year basis, one would use the areas under the NBE_t and PGE_t curves as represented by areas A on the upper graph and C on the lower graph to determine the BAF (i.e., $BAF_{\Sigma T}$= A/C or $BAF_{\Sigma T}$=

$NBE_{\Sigma T}/PGE_{\Sigma T}$). This results in a value of 0.334, which reflects the fact that the policy released most of the carbon long before T is reached.

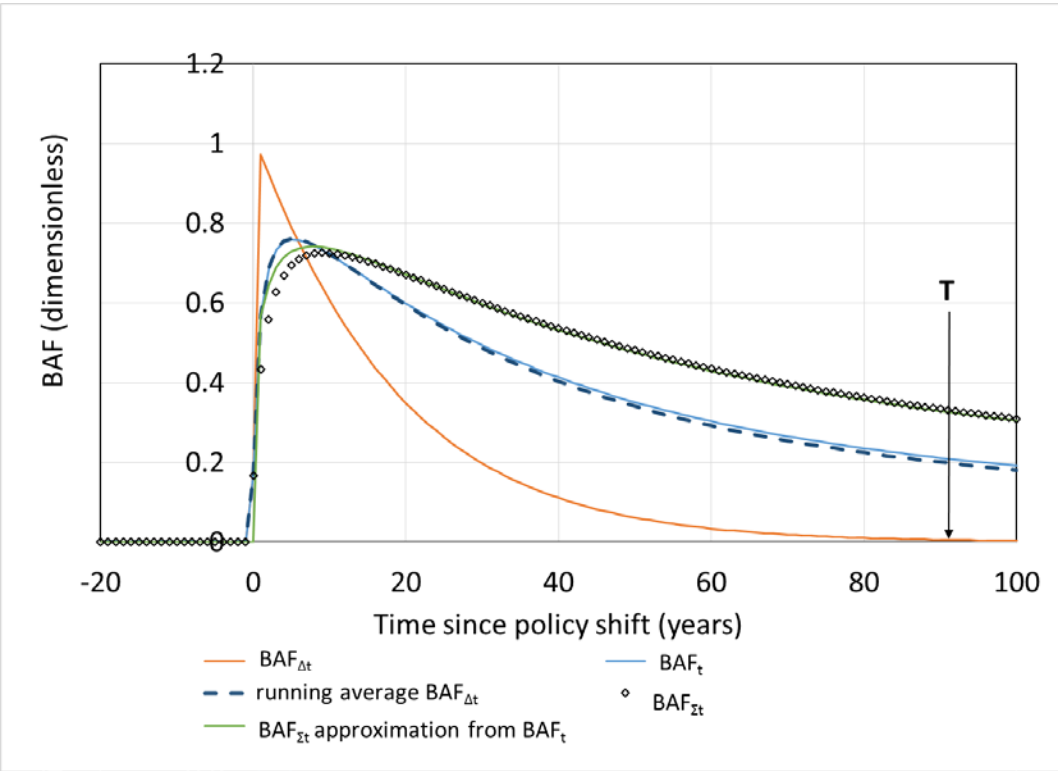

Figure B-6. The results of the various ways that BAF's can be calculated is shown on this figure. These BAF are calculated for a range of times (i.e., t), but the value at T can be determined using the vertical arrow at 90 years. $BAF_{\Delta t}$ reflects the year to year changes and is useful in identifying time T. However, because it is an "instantaneous" variable it does not represent the long-term effect of the policy. Solving the BAF at time T captures some of the cumulative effects of the policy (BAF_T=0.211) as does an approximation of BAF_T using a running average of $BAF_{\Delta t}$ (0.201) which indicates $BAF_{\Delta t}$ can be "scaled" up to BAF_t. This version of BAF appears to be similar that proposed in the 2014 EPA Framework documents and referred to there as the cumulative BAF. Solving the BAF over the time period T as represented by $BAF_{\Sigma T}$ results in a higher value at time T (0.334) reflecting the fact that the carbon release to the atmosphere are not all at time T, but occur gradually over time period T. Another

way to address this gradual release is to approximate $BAF_{\Sigma T}$ from BAF_T using the method described in Appendix A. This approximation is quite similar to $BAF_{\Sigma T}$ (0.329).

C. THEORETICAL EXAMPLES USING PROPOSED PGE, NBE, AND BAF TERMS

This appendix provides theoretical examples of various ways that additional biogenic carbon harvest could influence the stores of carbon in a landscape over time. These examples range from relatively simple cases in which biogenic carbon harvest leads to a loss or gain of carbon in the landscape to a complex case in which an initial decline is followed by an eventual increase in carbon stores. More complexity is added for two cases in which an environmental driver either leads to an increase or decrease in productivity over time. There are many other possible examples that could be explored, but these five examples provide insights into how the various PGE, NBE, and BAF relate to each other and respond to different situations.

While each case is described, one case (i.e., carbon loss) has been used in Appendix A to provide a graphical illustration of the various terms being proposed in the new framework equations.

The terms proposed are derived and fully explained in Appendix A; however a short summary follows:

PGE, NBE, and BAF are potential gross emissions, net biogenic emissions, and biogenic accounting factor, respectively. Each of these terms can be considered in multiple ways with respect to time and that is indicated by a subscript. To represent the value at any time the subscript t is used. To represent the rate of change at a particular time (i.e., the marginal rate of change) the subscript Δt is used. To indicate the time at which the effects of the biogenic harvest ceases to increase, the letter T is used. If T is used as a subscript it indicates values at time point T. To indicate the sum of the values over the interval T, the subscript ΣT is used. If the sum over an interval over t years is used, the subscript Σt is used to indicate that sums at various time intervals are being used. It is acknowledged that it would be simpler to not indicate which specific time concept is used; however not specifying the differences leads to confounding related concepts that need to be kept separate.

The following cases were generated using a simple input-output model programmed in Stella with one pool that represented the average stores in the landscape. More complex models could have been used, however, our intent was not to be hyper-realistic—it was to provide illustrations of very general types of situations. For example, the carbon loss case could represent a situation in which harvest interval is shortened or harvest intensity is increased to provide more material for biogenic fuel stock. It could also represent an increase in thinning or a diversion of long-live wood products into biofuels or many other situations. Examples of what the cases represent are provided as each case is described, but these examples are not intended to be exhaustive. It should also be borne in mind that these cases do not represent **what will** happen when biogenic carbon is harvested. They should be thought of as a sensitivity analysis to explore **what might** happen and how the various framework terms that are being proposed will play out.

The simulations represent a landscape and the biogenic feedstock harvest is maintained over the entire 100 year period simulated to assess the policy effect. The units on the vertical axes are expressed in the average store per area (i.e., Mg/ha or metric tonnes/ha). In addition a 50 year period prior to biofuel harvest was also simulated. Year zero is defined as the year the policy of increased biofuel harvest was initiated. All the numbers generated for these cases started with the stores of carbon in two cases: a

reference case to represent "business as usual" conditions without increased feedstock harvesting and a policy case to represent increased harvests of biogenic feedstocks. The model was parameterized to represent a system dominated by a long-lived perennial such as trees. The absolute values of stores should be taken as rough numbers and they are not intended to represent any particular system.

Case 1: Loss of Carbon

This is a relative simple case in which harvest in a forest landscape is increased to provide biogenic fuel stock. The input (i.e., the net primary production (NPP) or alternatively gross growth) to both the reference and policy scenarios remains the same. The difference is that the outputs (i.e, removal of carbon from the land) from the policy case are 20% higher than that for the reference scenario. Specifically, the rate-constant defining output (i.e. the annual carbon loss) was increased from 0.05 (≈5%) per year in the reference case to 0.06 (≈6%) per year in the policy case to represent an increased harvest rate. This general case could represent a number of specific situations including: a decrease in the harvest interval; an increase in harvest intensity (additional thinnings or salvage); or alternatively it could represent a diversion of harvested wood from long-term wood products that store carbon to biofuel use that does not, essentially shortening the life-time of terrestrial carbon.

Because this is the first case examined, additional details on terms and calculations is provided here.

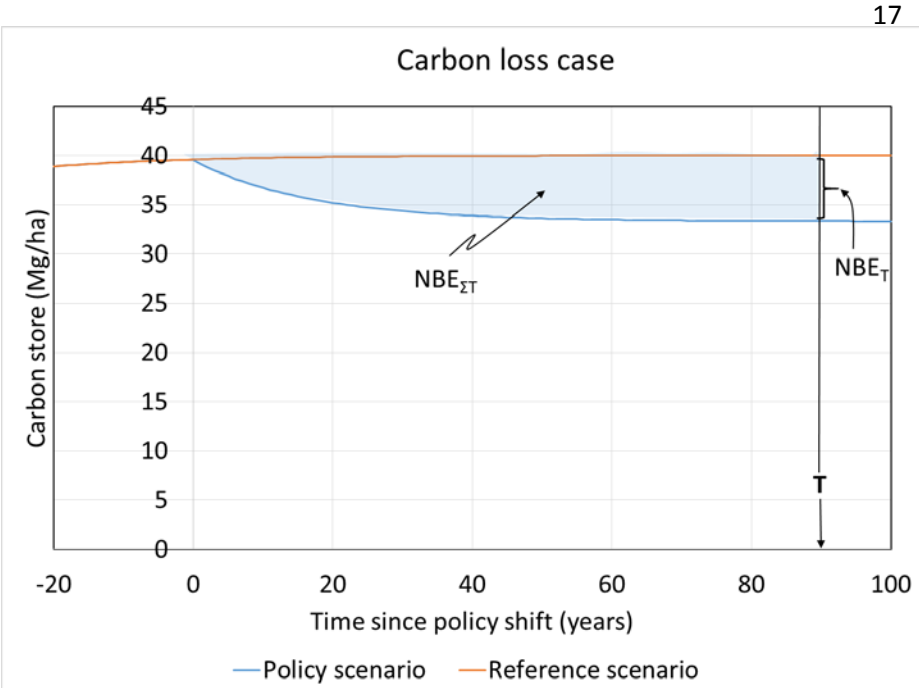

Figure C-1. The landscape level average carbon stores when harvest for biofuels (the policy scenario) leads to a decreases in stores compared to the reference scenario. Capital T indicates the time at which the differences between the scenarios ceases to change. The difference between scenarios at time T is NBE_T, the sum of the differences (i.e., the "wedge") is indicated by the shaded area and $NBE_{\Sigma T}$.

Since the policy scenario results in a higher proportion of carbon being harvested, the carbon store of the policy scenario declines relative to the reference scenario (Figure 1). In theory an increase in losses from the landscape from 0.05 per year to 0.06 per year should lead to the policy scenario eventually storing 0.05/0.06=83% of the carbon of the reference scenario. The simulations resulted in exactly the same difference. This difference does not expand endlessly, but appears to cease growing 80-90 years after the policy in introduced.

The time course of $NBE_{\Delta t}$ indicates that the differences between the two scenarios ceases to grow at 90 years, which, as discussed in Appendix A, indicates that T is 90 years (Figure 2). It is also evident that the greatest loss of carbon in this case occurs immediately after the policy is adopted. The annual potential gross emissions does not stay constant. This slight decline in the absolute amount harvested and used as biofuel is caused by the negative feedback present between harvest and the landscape. If a constant proportion of the landscape carbon store is harvested and this harvest reduces the store to be harvested, then absolute amount harvested must decline somewhat as a new age structure is imposed on the landscape.

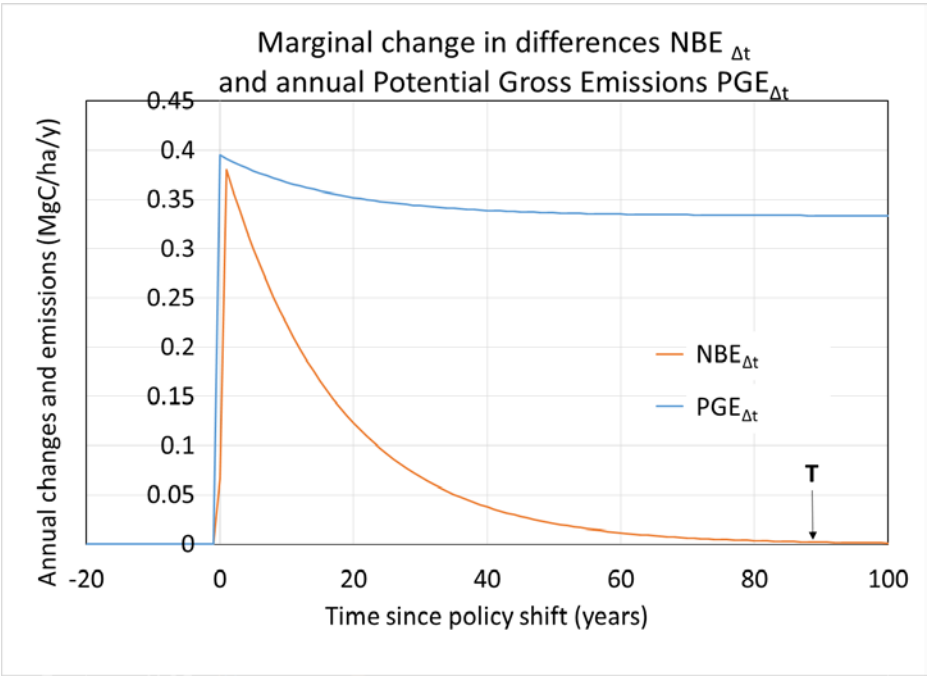

Figure C-2. The rate at which the difference between the reference and policy scenarios is growing ($NBE_{\Delta t}$) and the potential gross emissions from biofuel use each year ($PGE_{\Delta t}$) when there is a loss of carbon caused by the policy scenario.

When the differences in scenario stores and the cumulative potential emissions at any time is examined the differences (i.e., the wedge) between the scenario ceases to grow, but the cumulative potential gross emissions continues to increase as long as harvests occur (Figure 3). This indicates that if one were to use the ratio of the NBE_t and PGE_t terms to calculate the BAF_t, then its value decreases over time.

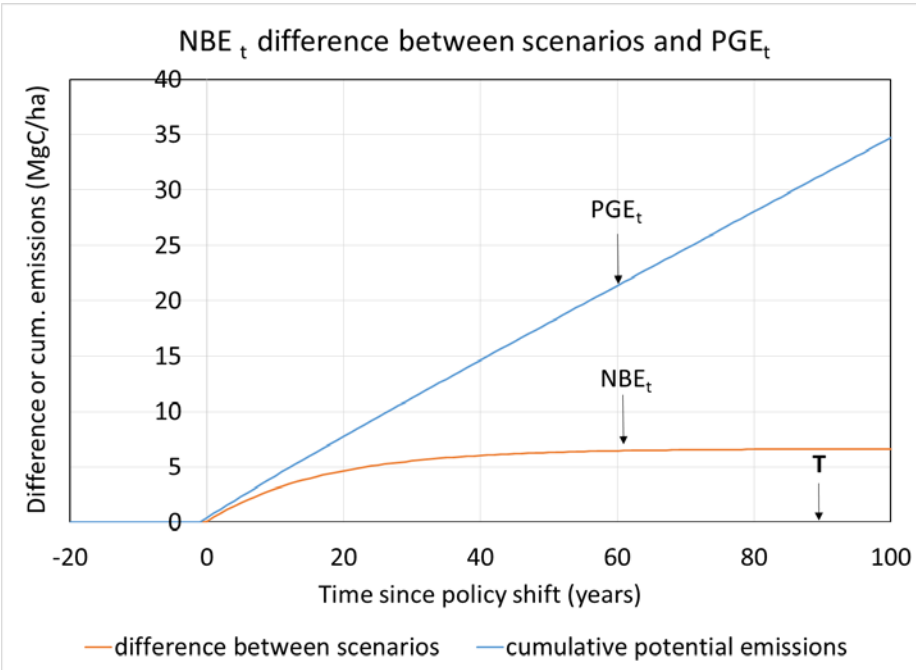

Figure C-3. The time course of the difference between scenarios (NBE_t) and cumulative potential gross emissions (PGE_t) when there is a loss of carbon caused by the policy scenario.

The BAF term can be calculated using different temporal concepts, the result of these calculations is shown in Figure 4. Regardless of how the BAF is calculated, the value rises and then declines over time. Considered over a long enough time period, all these BAF's would approach zero. The marginal rate that the BAF changes, as indicated by $BAF_{\Delta t}$, approaches zero at 90 years, reflecting the fact that the difference in stores between the two scenarios ceases to change at this point. This $BAF_{\Delta t}$ value corresponds to EPA's "per-period" BAF because it takes into account only changes in emissions at a single point in time. However, using $BAF_{\Delta t}$ values during the latter part of the time period would ignore the times when by $BAF_{\Delta t}$ was a positive number. Calculating the BAF at the end of a time period is represented by the BAF_t curve. This value corresponds to EPA's "cumulative" BAF and equals 0.211 at time T. BAF_t reflects some of the "cumulative" effects as it is based on the cumulative difference in stores and the cumulative emissions (the ratio of NBEt and PGEt) at a given time. However, it does not represent all the cumulative effects on the atmosphere (see below). It can be approximated by calculating a running average of $BAF_{\Delta t}$ over a time period which at time T has a value of 0.201.

We are proposing that EPA consider the "total cumulative" effects of the differences of atmospheric carbon for each year over the entire time period T to account for both the long-term outcome as well as the long-term residence time of carbon dioxide emissions. To calculate $BAF_{\Sigma T}$, one sums the NBE_t and PGE_t values over time period T as represented by the $BAF_{\Sigma t}$ curve. This version of the BAF does not rise as high as the BAF_t curve but it is considerably higher at time T (0.334). An approximation of $BAF_{\Sigma T}$ that scales BAF_t behaves similarly to $BAF_{\Sigma t}$ for the later times, but it is slightly higher early on; it has a value of 0.329 at time T.

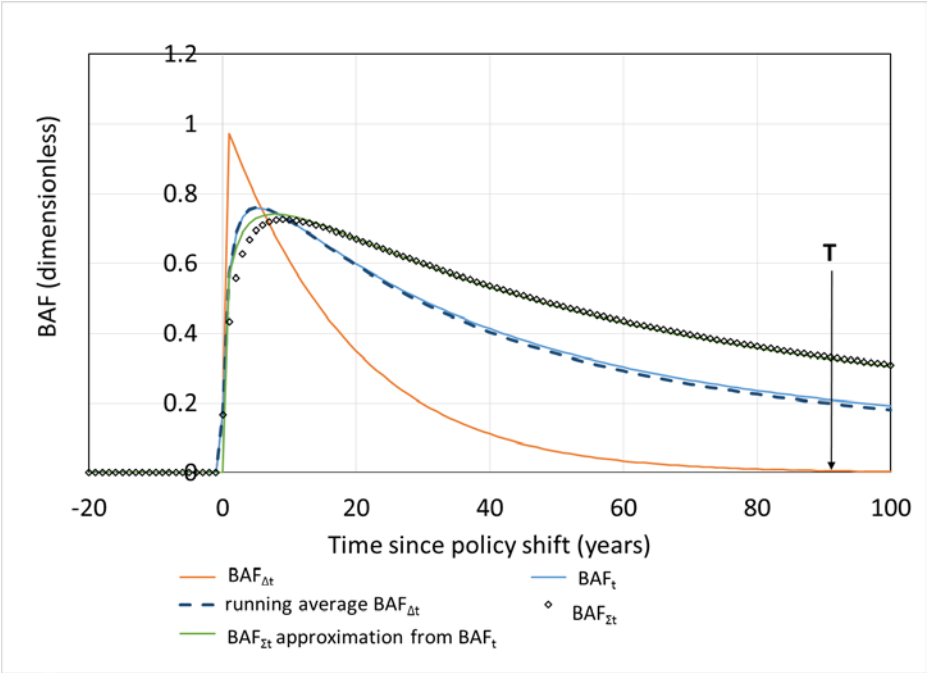

Figure C-4. Comparison of BAF calculation methods for the case in which biofuel harvest reduces carbon stores relative to the reference scenario.

Case 2: Gain of Carbon

This is another simple case and although there is an increase in carbon losses similar to Case 1 due to increased harvesting, there is also an increase in the input in the policy case of 50%. This increased input of carbon could derive from a range of specific situations: use of a growing stock that grows faster; practices that improve productivity such as irrigation or fertilization; and planting on lands that had shorter-lived plants. Theoretically the greater increase in inputs (50%) relative to outputs (20%) should lead to the policy scenario eventually storing 25% more carbon than the reference scenario (specifically the ratio of inputs to outputs for the policy scenario are 1.5/0.06=25 and that for the reference scenario is 1/0.05=20).

In the case in which the policy case gains carbon relative to the reference case, the timing of the changes is similar to that observed in Case 1 with the differences between the scenarios ceasing to change in 80-90 years; however the carbon stores in the policy case are 24.9% higher than that for the reference case (Figure C-5).

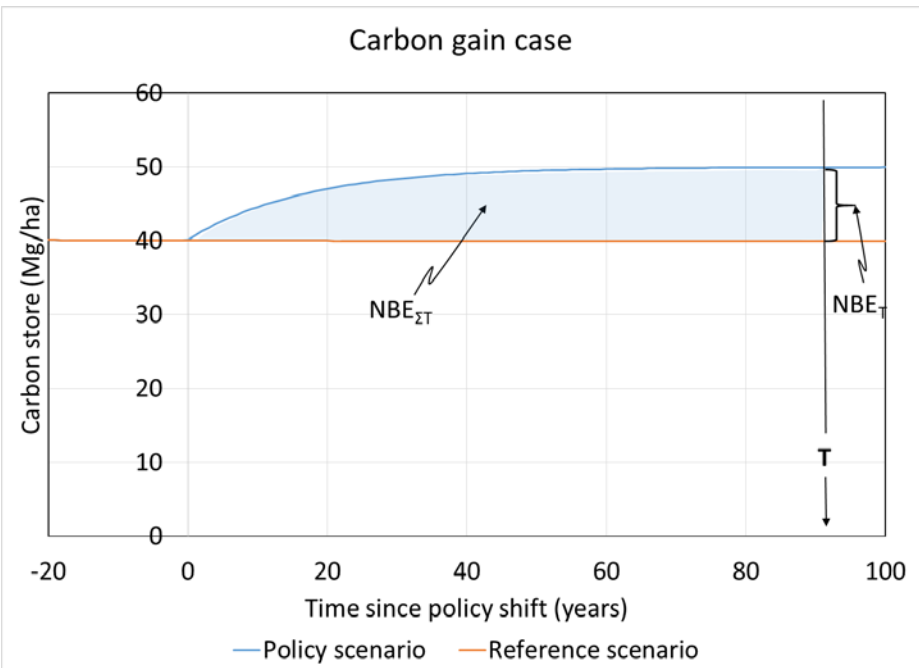

Figure C-5. The landscape level average carbon stores for the case when harvest for biofuels (the policy scenario) leads to a increases in stores compared to the reference scenario. Capital T indicates the time at which the differences between the scenarios ceases to change. The difference between scenarios at time t is NBE_t, the sum of the differences (i.e., the "wedge") is indicated by the shaded area and $NBE_{\Sigma T}$.

The time course of $NBE_{\Delta t}$ indicates that the differences between the two scenarios ceases to grow at 90 years, which indicates that T is 90 years (Figure 6). It is also evident that the greatest gain of carbon in this case occurs immediately after the policy is adopted. Note that a gain in landscape carbon is represented as a loss to the atmosphere; therefore $NBE_{\Delta t}$ is a negative number. The annual potential gross emissions does not stay constant in this case. There is an increase in the absolute amount harvested and used as biofuel that is caused by the fact that if the actions are taken in the policy case to, for example, increase growth rates which results in more carbon to harvest.

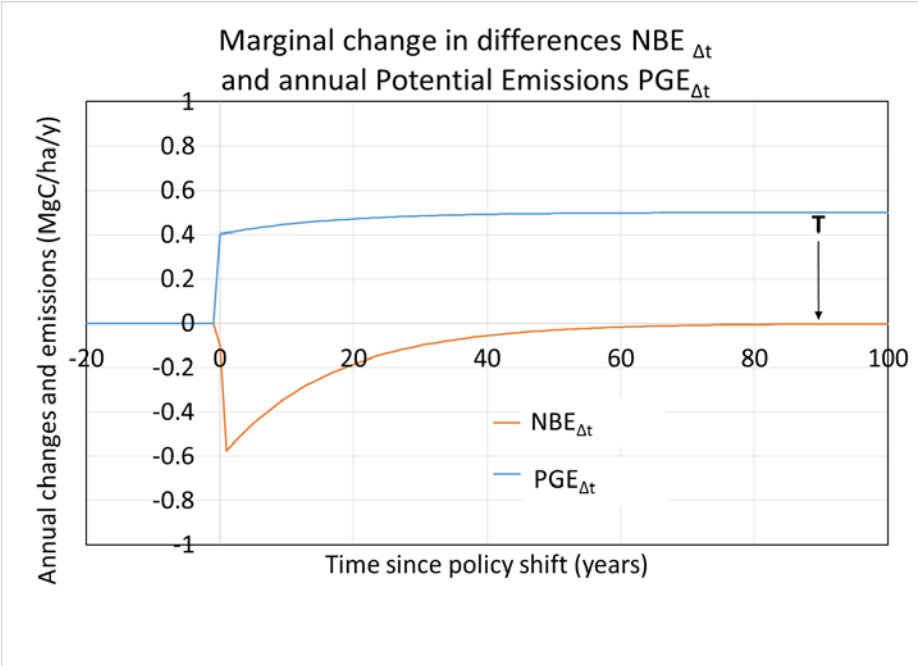

Figure C-6. The rate at which the difference between the reference and policy scenarios is growing ($NBE_{\Delta t}$) and the potential gross emissions from biofuel use each year when there is a gain of carbon caused by the policy scenario.

While the differences in scenario stores (NBE_t) stabilizes (i.e., ceases to grow), the cumulative potential gross emissions continues to increase as long as harvests occur (Figure C-7). This indicates that if one were to use the ratio of the NBE_t and PGE_t terms to calculate the BAF_t, then its value decreases at time increases. Note that this also occurs in Case 1 when carbon losses are induced by biofuel harvest.

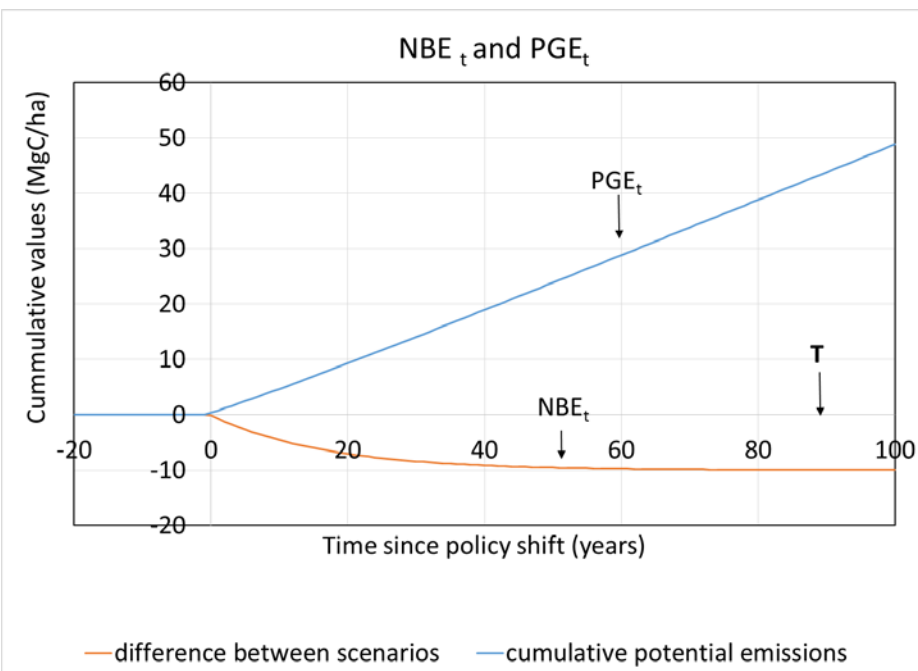

Figure C-7. The time course of the difference between scenarios (NBE_t) and cumulative potential gross emissions (PGE_t) when there is a gain of carbon caused by the policy scenario.

As displayed in Case 1, the BAF term can be calculated using different temporal concepts. For the carbon gain case, the result of these calculations is shown in Figure 8. Regardless of how the BAF is calculated, the value falls and then rises over time and considered over a long enough time period all these BAF's would approach zero. The marginal rate that the BAF changes, as indicated by $BAF_{\Delta t}$, approaches zero (-0.005) at 90 years, reflecting the fact that the difference in stores between the two scenarios ceases to grow at this point. However, using $BAF_{\Delta t}$ values during the latter part of the time period would ignore the times when by $BAF_{\Delta t}$ was a negative number. The BAF_t curve and its approximation using a running average of $BAF_{\Delta t}$ over a time period does not equal zero at time T (-0.227 and -0.243)). While these BAFs reflect some of the "cumulative" effects at a given time, it does not address the "total cumulative" effects over the entire time period T as represented by the $BAF_{\Sigma t}$ curve. The $BAF_{\Sigma t}$ version of the BAF does not fall as low as the BAF_t curve and it is considerably lower at time T (-0.377). An approximation of $BAF_{\Sigma T}$ that scales BAF_t behaves similarly to $BAF_{\Sigma t}$ and has a value of -0.378 at time T.

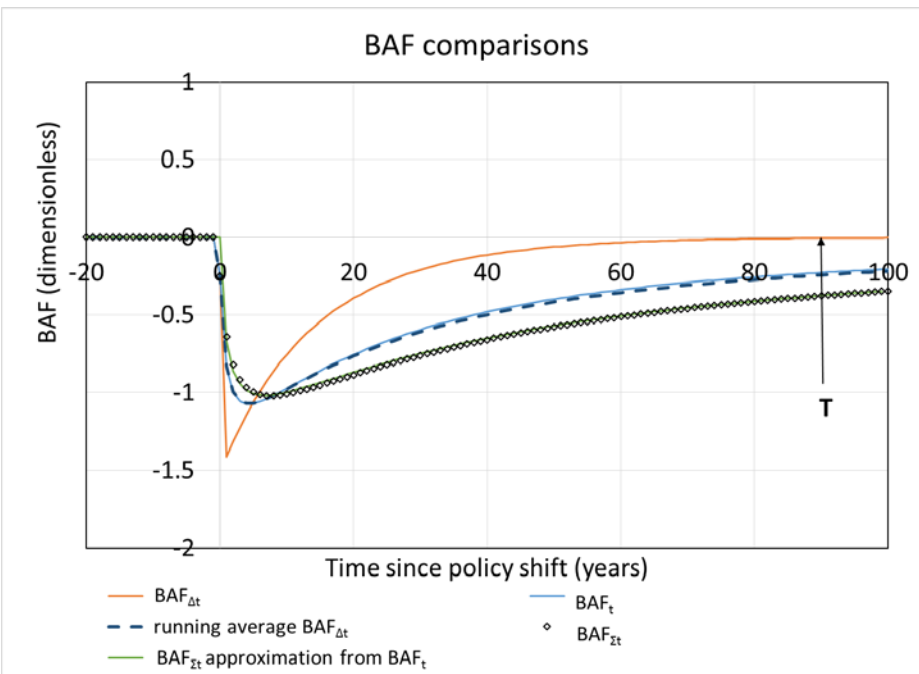

Figure C-8. Comparison of BAF calculation methods for the case in which biofuel harvest increases carbon stores relative to the reference scenario.

Case 3: Complex Response: Loss then Gain of Carbon

This case is more complex than Cases 1 and 2 because it indicates what might happen if there is an initial loss of carbon, but this is countered by practices that eventually increase the productivity of the landscape in the policy scenario. This might include planting additional area, using faster growing plants, or fertilization. The difference relative to Case 2 is that there is a 5 year lag between the initial increase in harvest and subsequent increases in the landscape inputs due to human intervention.

In the case in which the policy case initially loses and then eventually gains carbon relative to the reference case, the differences between the scenarios is a combination of Cases 1 and 2, with a short period of carbon loss followed by a longer period of carbon gain that ceases at 80 years (Figure C-9). For this case the timeframe used to evaluate the policy effect is absolutely crucial: too short a period would indicate a loss, but ignoring the short-term loss would overestimate the net gain over the time period T. The longer the lag in the practices leading to the ultimate gain, the more important the timeframe likely becomes.

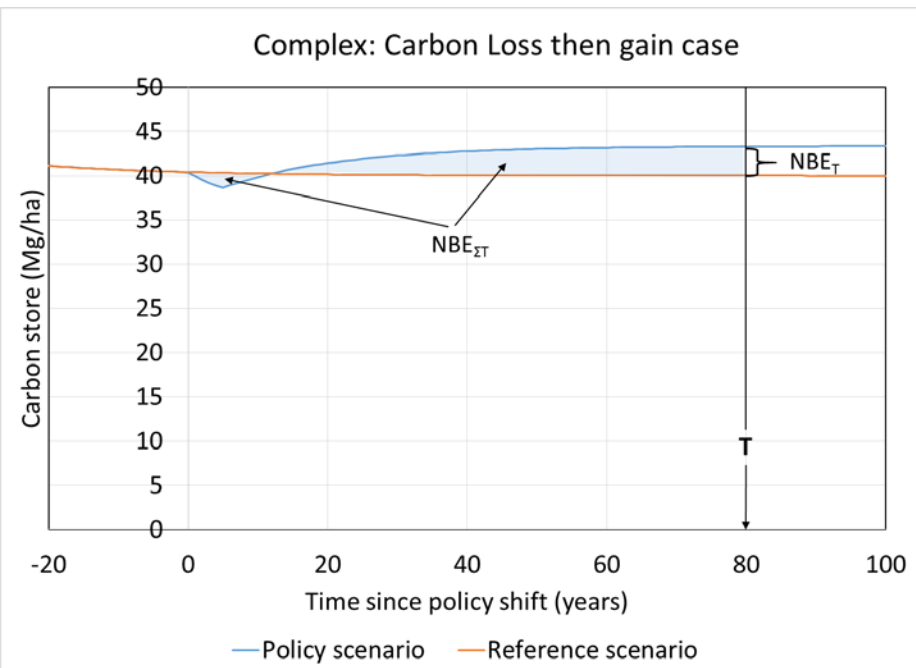

Figure C-9. The landscape level average carbon stores for the case in which harvest for biofuels (the policy scenario) leads to an initial decrease, but an eventual increase in carbon stores compared to the reference scenario. Capital T indicates the time at which the differences between the scenarios ceases to change. The difference between scenarios at time t is NBE_t, the sum of the differences (i.e., the "wedge") is indicated by the shaded area and $NBE_{\Sigma T}$.

The time course of $NBE_{\Delta t}$ indicates that the differences between the two scenarios ceases to grow at 80 years, which indicates that T is 80 years (Figure C-10). The greatest loss of carbon in this case occurs immediately after the policy is adopted, but the greatest gain is immediately after the practices that increase landscape inputs is implemented. The annual potential gross emissions does not stay constant and reflects a combination of what happened in Cases 1 and 2. The slight decline in the absolute amount harvested and used as biofuel is caused by the negative feedback present between harvest and the landscape. However, the slight increase in potential gross emissions each year is caused by the fact that increasing input leads to more carbon to be harvested from the landscape.

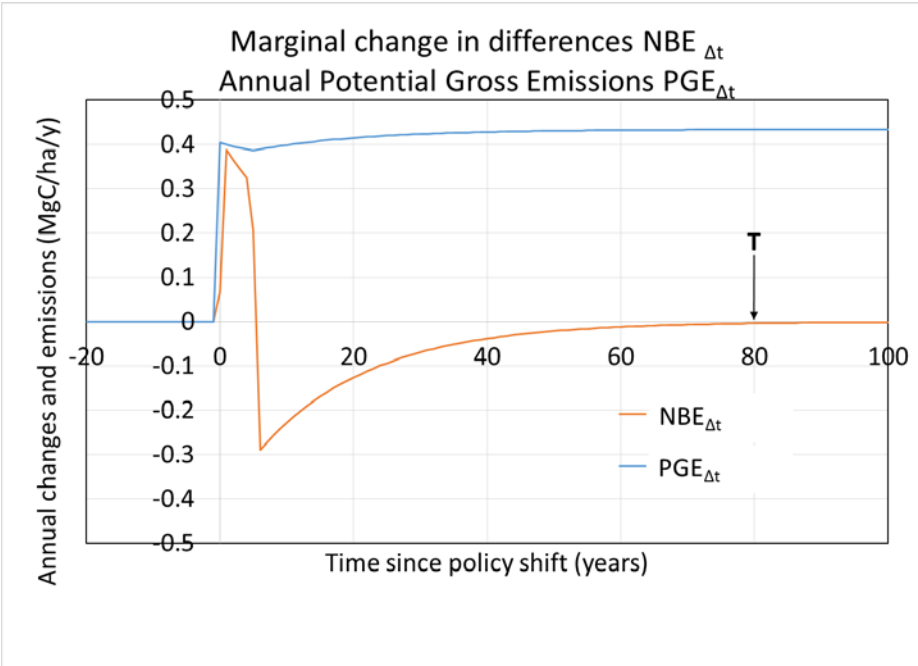

Figure C-10. The rate at which the difference between the reference and policy scenarios is growing ($NBE_{\Delta t}$) and the potential gross emissions from biofuel use each year when there is a loss then a gain of carbon caused by the policy scenario.

While the differences in scenario stores (NBE_t) stabilizes (i.e., ceases to grow), the cumulative potential gross emissions continues to increase as long as harvests occur (Figure 11). This indicates that if one were to use the ratio of the NBE_t and PGE_t terms to calculate the BAF_t, then its value decreases over time. Note that this also occurs in Cases 1 and 2.

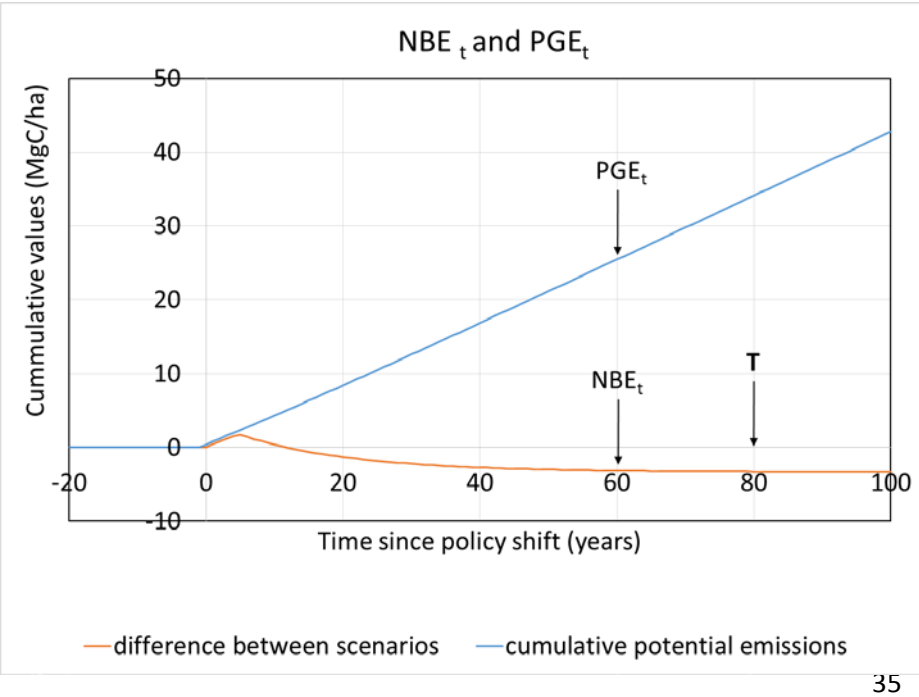

Figure C-11. The time course of the difference between scenarios (NBE_t) and cumulative potential gross emissions (PGE_t) when there is a loss then gain of carbon caused by the policy scenario.

As in the other cases the BAF term can be calculated using different temporal concepts, the result of these calculations for the carbon gain case is shown in Figure 12. Regardless of how the BAF is calculated the value rises, falls and then rises over time and considered over a long enough time period all these BAF's would approach zero. In this particular case the values of the BAF's are similar at time T. The marginal rate that the BAF changes, as indicated by $BAF_{\Delta t}$, approaches zero (-0.005) at 80 years, reflecting the fact that the difference in stores between the two scenarios ceases to grow at this point. However, using this term as the BAF is very misleading because it ignores the times when by $BAF_{\Delta t}$ was a very different number. The BAF_t curve and its approximation using a running average of $BAF_{\Delta t}$ over a time period does not quite equal zero at time T (-0.0949 and -0.0953, respectively). While these BAFs reflect some of the "cumulative" effects at a given time, it does not address the "total cumulative" effects of the additions over the entire time period T as represented by the $BAF_{\Sigma t}$ curve. The $BAF_{\Sigma t}$ version of the BAF is more dampened than the BAF_t curve but is about the same value at time T (-0.118). An approximation of $BAF_{\Sigma T}$ that scales BAF_t behaves similarly to $BAF_{\Sigma t}$ and has a value of -0.120 at time T.

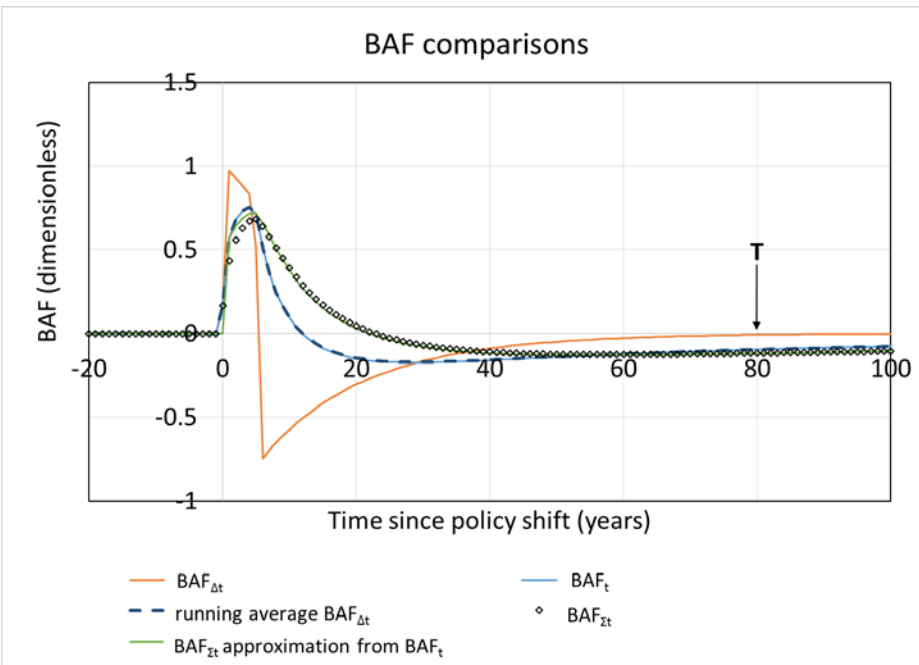

Figure C-12. Comparison of BAF calculation methods for the case in which biofuel harvest decreases and then increases carbon stores relative to the reference scenario.

Case 4: No Steady-state-Increasing System Input

Cases 1-3 represented situations in which the underlying environmental controls of the landscape were constant (e.g., temperature, precipitation, nutrient availability). In Case 4, the environment is changing in a way that enhances the ability of system to remove carbon from the atmosphere over time. This might represent a situation in which nitrogen availability is increasing due to atmospheric inputs related to pollution which would in turn lead to an increase in net productivity and hence carbon inputs to both the reference and the policy scenarios. It might also represent the effect of carbon dioxide fertilization due to increasing concentrations of this gas in the atmosphere.

In this case a difference in carbon stores develops between the reference and policy scenarios; however, the carbon stores of both scenarios is increasing over time (Figure C-13). Unlike Cases 1-3, defining T is challenging, in part because the difference between the scenarios continues to expand even at the end of the simulation period. However, after 90 years the difference between scenarios is not growing at a fast rate, and we have assumed that T would be 90 years in this case. However, defining T in a case such as this remains an open question.

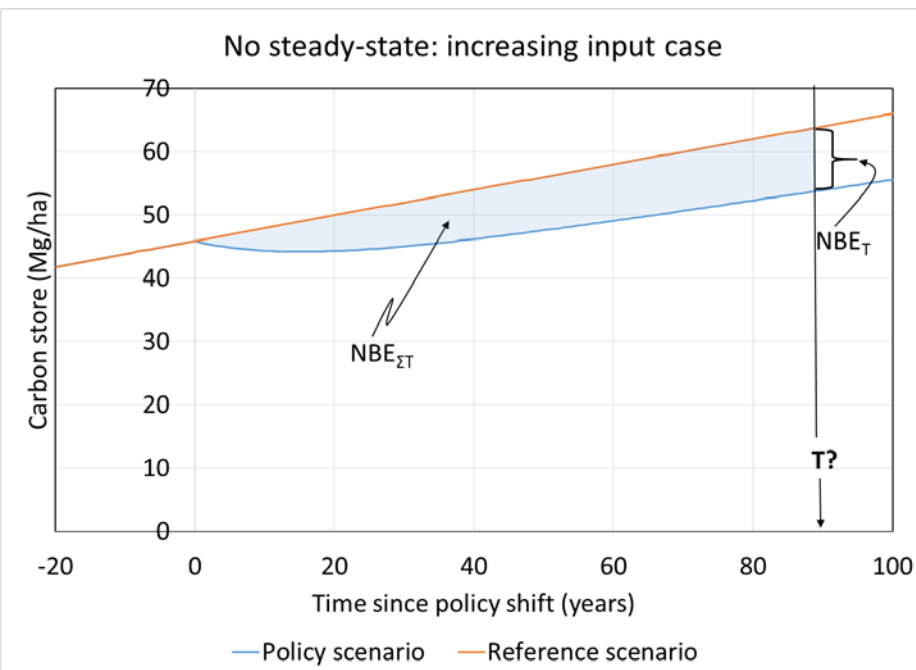

Figure C-13. The landscape level average carbon stores for the case in which harvest for biofuels (the policy scenario) leads to a decrease in carbon stores compared to the reference scenario, but both scenarios have increasing carbon stores relative to time 0. Capital T indicates the time at which the differences between the scenarios ceases to change. The difference between scenarios at time t is NBE_t, the sum of the differences (i.e., the "wedge") is indicated by the shaded area and $NBE_{\Sigma T}$.

The time course of $NBE_{\Delta t}$ indicates that the differences between the two scenarios continues to grow at 90 years, but that the rate at which the difference is increasing is relatively constant. This is indicated by the fact that $NBE_{\Delta t}$ asympotes to a value of 0.035 MgC/ha/year by 90 years (Figure 14). This may indicate when the effect caused by the policy has been completely realized; however, it is the interaction

of the policy with the underlying environmental driver that prevents $NBE_{\Delta t}$ from reaching zero at 90 years. If the environment stabilizes, then one would expect $NBE_{\Delta t}$ to eventually reach zero. In this case we have assumed that T is 90 years, but one could argue it is never reached as long as the environment keeps changing in one direction relative to productivity controls. The greatest loss of carbon in this case occurs immediately after the policy is adopted, but loss continues the entire 100 year simulation period. The annual potential gross emissions does not stay constant and in fact steadily increases over time because increasing input leads to more carbon being harvested from the landscape.

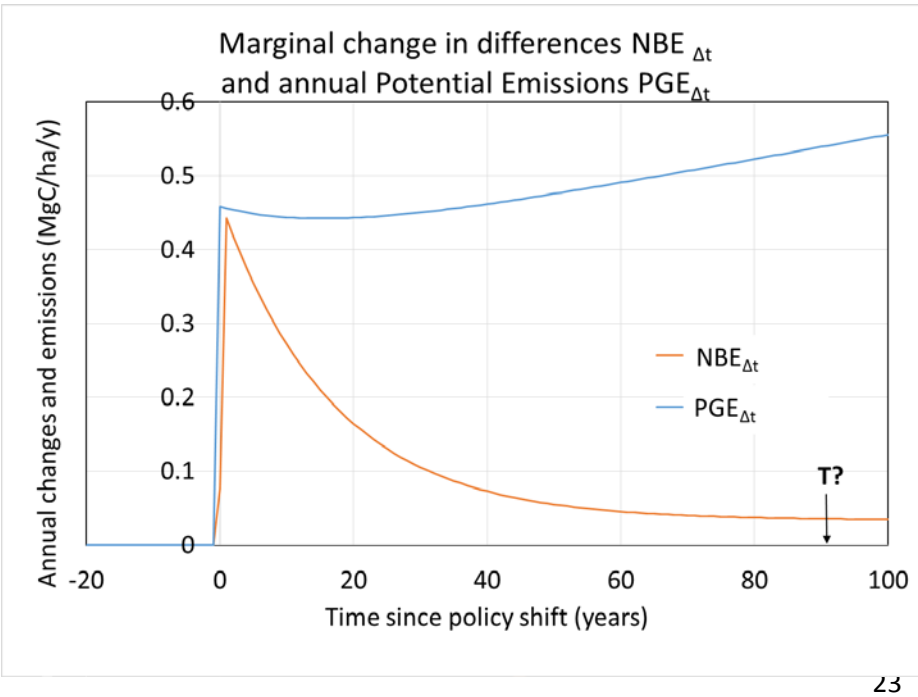

Figure C-14. The rate at which the difference between the reference and policy scenarios is growing ($NBE_{\Delta t}$) and the potential gross emissions from biofuel use each year when both the reference and the policy scenario have an increase in input related to an environmental change.

When the differences in scenario stores and the cumulative potential emissions at any time is examined the differences between the scenarios continues to grow after 90 years, but the cumulative potential gross emissions continues to increase at a much faster rate (Figure 15). This indicates that if one were to use the ratio of the NBE_t and PGE_t terms to calculate the BAF_t, then its value decreases over time although not as quickly as in Cases 1-3.

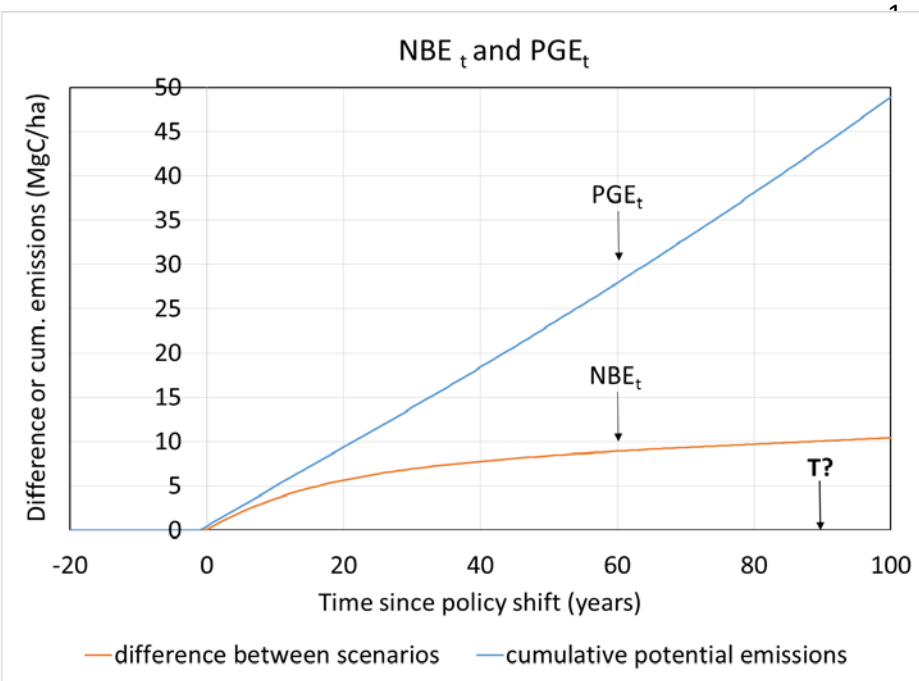

Figure C-15. The time course of the difference between scenarios (NBE_t) and cumulative potential gross emissions (PGE_t) when both the reference and the policy scenario have an increase in input related to an environmental change.

As in the other cases the BAF term can be calculated using different temporal concepts, the result of these calculations for the case when landscape input steadily increase is shown in Figure 16. Regardless of how the BAF is calculated the value rises and then falls over time. Unlike Cases 1-3 it is not clear that any of the BAF's will reach zero as long as the environment is causing landscape input to increase. In this particular case the values of the BAFs are very different at time T. The marginal rate that the BAF changes, as indicated by $BAF_{\Delta t}$, approaches 0.065 at 90 years. The BAF_t curve and its approximation using a running average of $BAF_{\Delta t}$ over a time period are 0.23 and 0.24, respectively at time T. $BAF_{\Sigma t}$ curve is more dampened than the BAF_t curve and it has a higher value at time T (0.344). An approximation of $BAF_{\Sigma T}$ that scales BAF_t behaves similarly to $BAF_{\Sigma t}$ for the later times, but it is slightly higher early on; it has a value of 0.344 at time T.

Despite the fact that inputs are changing the BAFs resulting from this case are only slightly higher than those for Case 1. This may indicate, that despite some underlying environmental changes and uncertainty about T, the BAF is similar to within at least 1 decimal place.

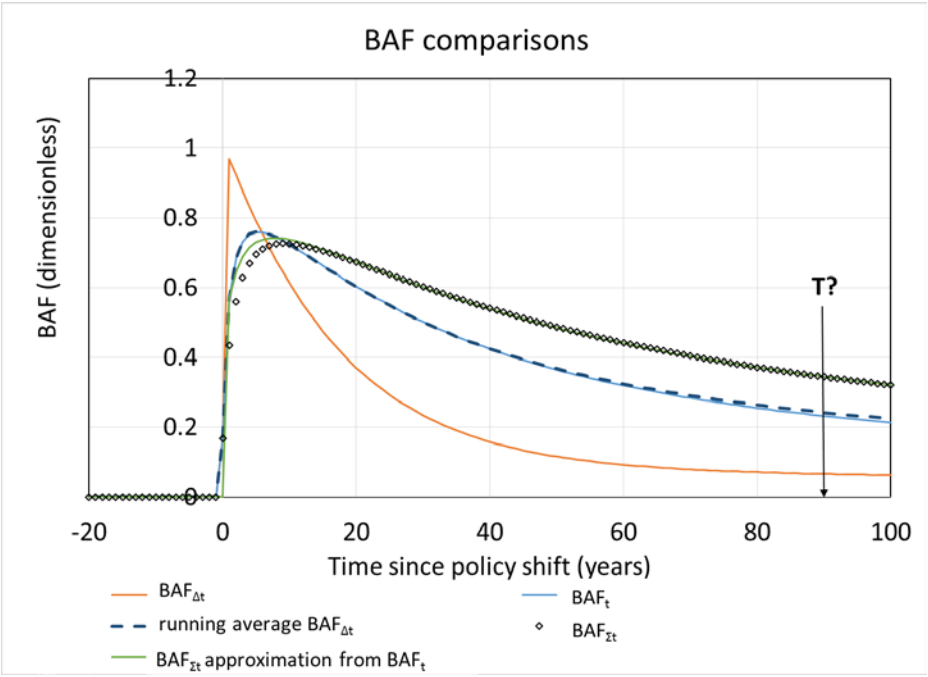

Figure C-16. Comparison of BAF calculation methods for the case when both the reference and the policy scenario have an increase in input related to an environmental change.

Case 5: No Steady-state-Decreasing System Input

Case 5 represent a situation in which the environment for both scenarios is changing; however in this case the environment is becoming *less* favorable for landscape input and hence carbon storage. This might represent a case in which available moisture is decreasing due to climate change, leading to a decrease in NPP in both scenarios.

In this case a difference in carbon stores develops between the reference and policy scenarios; however, the carbon stores of both scenarios is decreasing over time (Figure C-17). As with Cases 4, defining T is challenging, in part because the difference between the scenarios continues to contract even at the end of the simulation period. However, after 90 years the difference between scenarios is not growing at a fast rate, and we have assumed that T would be 90 years in this case. However, how to define T in a case such as this remains an open question.

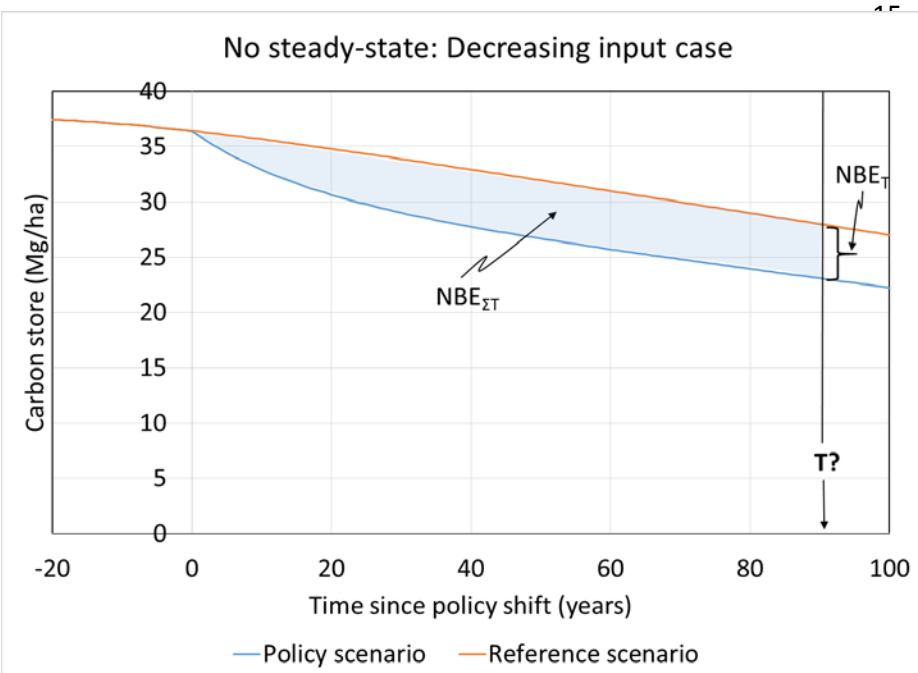

Figure C-17. The landscape level average carbon stores for the case when increased harvest for biofuels (the policy scenario) leads to a decrease in carbon stores compared to the reference scenario, but both scenarios have decreasing carbon stores relative to time 0 caused by an environmentally driven decline in inputs. Capital T indicates the time at which the differences between the scenarios ceases to change. The difference between scenarios at time t is NBE_t; the sum of the differences (i.e., the "wedge") is indicated by the shaded area and $NBE_{\Sigma T}$.

The time course of $NBE_{\Delta t}$ indicates that the differences between the two scenarios continues to grow at 90 years, but that the rate at which the difference is increasing is relatively constant. This is indicated by the fact that $NBE_{\Delta t}$ asympotes to a value of -0.014 MgC/ha/year by 90 years (Figure C-18). As in Case 4 this may indicate that this when the effect caused by the policy has been completely realized; however, it is the interaction of the policy with the underlying environmental driver that prevents $NBE_{\Delta t}$ from reaching zero at 90 years. If the environment stabilizes, then one would expect $NBE_{\Delta t}$ to eventually reach zero. In this case we have assumed that T is 90 years, but one could argue it is never reached as long as the environment keeps changing in one direction relative to productivity controls. much later. The greatest loss of carbon in this case occurs immediately after the policy is adopted and the loss starts to shrink 55 years after the policy is adopted and it continues the rest of the 100 year simulation period. The annual potential gross emissions does not stay constant and in fact steadily decreases over time because decreasing input leads to less carbon to be harvested from the landscape as time progresses.

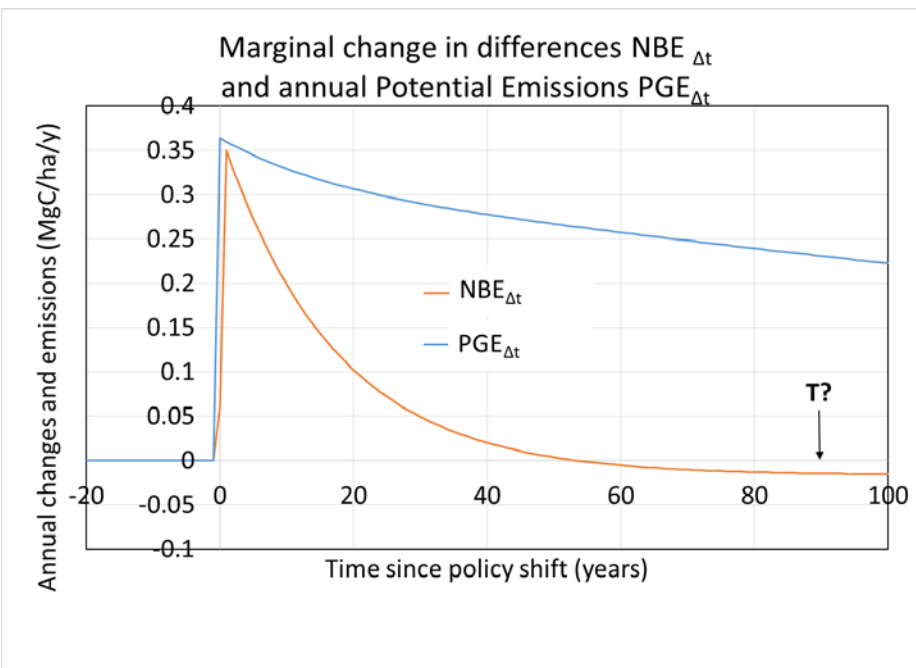

Figure C-18. The rate at which the difference between the reference and policy scenarios is growing ($NBE_{\Delta t}$) and the potential gross emissions from biofuel use each year when both the reference and the policy scenario have a decrease in input related to an environmental change.

When the differences in scenario stores and the cumulative potential emissions at any time is examined the differences (i.e., the wedge) between the scenarios continues to grow until 55 year after the policy shift, but after this point it decreases. This is caused by the fact that decreasing inputs are impacting both scenarios and they are converging on the same lower value. In contrast the cumulative potential gross emissions continues to increase the entire period although not as quickly as in Case 4 (Figure 19).

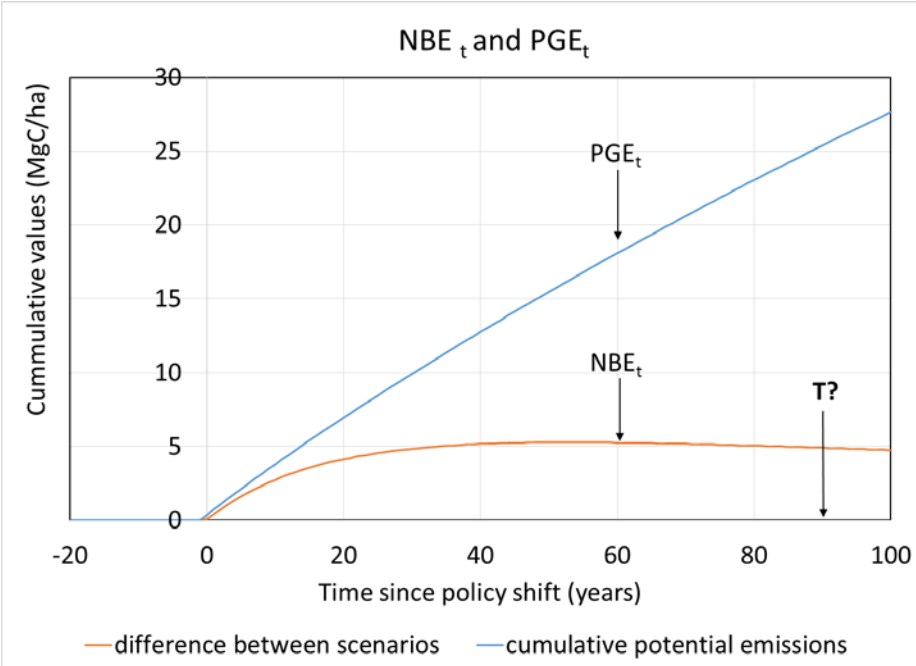

Figure C-19. The time course of the difference between scenarios (NBE_t) and cumulative potential gross emissions (PGE_t) when both the reference and the policy scenario have a decrease in landscape input related to an environmental change.

As in the other cases the BAF term can be calculated using different temporal concepts, the result of these calculations for the carbon gain case is shown in Figure C-20. Regardless of how the BAF is calculated the value rises and then falls over time. Unlike Cases 1-3, but similar to Case 4 it is not clear that any of the BAF's will reach zero as long as the environment is causing landscape input to decrease. In this particular case the values of the BAF's are very different at time T. The marginal rate that the BAF changes, as indicated by $BAF_{\Delta t}$, approaches -0.064 at 90 years. The BAF_t curve and its approximation using a running average of $BAF_{\Delta t}$ over a time period are 0.193 and 0.162, respectively at time T. $BAF_{\Sigma t}$ curve is more dampened than the BAF_t curve and it has a higher value at time T (0.326). An approximation of $BAF_{\Sigma T}$ that scales BAF_t behaves similarly to $BAF_{\Sigma t}$ for the later times, but it is slightly higher early on; it has a value of 0.317 at time T. Despite the fact that inputs are changing the BAFs resulting from this case are only slightly higher than those for Case 1. This may indicate, that despite some underlying environmental changes and uncertainty about T that the BAF is similar to case within at least 1 decimal place.

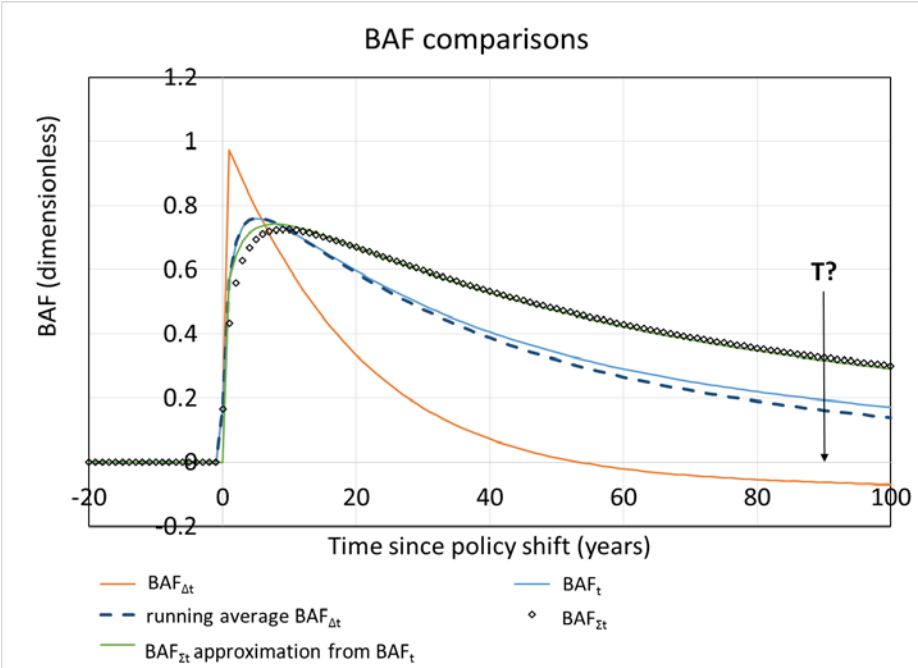

Figure C-20. Comparison of BAF calculation methods for the case when both the reference and the policy scenario have a decrease in input related to an environmental change.

Summary of Cases Regarding BAF

For the simple cases of decreasing or increasing carbon stores relative to the reference case caused by the policy, the BAF's are consistently positive or negative depending on the case (Table 1). When there is an underlying change in the environment, then the sign of the BAF can change particularly when the $BAF_{\Delta t}$ (the marginal or EPA's per-period) rate is used. However, for the other forms of BAF, the sign is consistent across the different methods for calculating the BAF, which indicates that at least the sign of the BAF is stable regardless of the timeframe used and the changing ability of the landscape to input carbon. It also seems to be the case these underlying environmental changes may not be changing the magnitude of the BAF at least one decimal point. For example, for the $BAF_{\Sigma T}$ value all the values when there is an increase in harvested related to biofuels are in the range of 0.33 to 0.34. The same insensitivity to the degree of environmental change appears for the $BAF_{\Sigma T}$ approximation using BAF_t from 0.37 to 0.344. For Case 3, which had a complex response, the BAF terms (except the marginal rate represented by $BAF_{\Delta t}$) are somewhat similar. This may indicate that when the net differences in scenarios is small, there is little difference in the terms as long as they are not based on the marginal changes.

Table 1 also shows that for given case, the value of the BAF differs widely depending on the method used for calculating it. In cases in which the BAF is positive and the policy scenario leads to a decrease in carbon stocks relative to the reference scenario, both the BAF_T and the $BAF_{\Delta t}$ tend to be lower than the proposed $BAF_{\Sigma T}$. In the cases in which the BAF is negative and the policy scenario leads to a

decrease in carbon stocks relative to the reference scenario, both the BAF_T and the $BAF_{\Delta t}$ tend to be higher (e.g., less negative) than the proposed $BAF_{\Sigma T}$.

Table 1. Summary of BAF values for using different timeframes for the five cases examined. The reported value is for T which in most cases is 90 years after the policy was implemented.

BAF term	Case 1: Decrease	Case 2: Increase	Case 3: Decrease-Increase	Case 4: Increasing inputs	Case 5: Decreasing Inputs
$BAF_{\Delta t}$ (EPA's Per-Period rate)	0.006	-0.005	-0.005	0.065	-0.064
BAF_t (EPA's Cumulative Emission-Based rate)	0.211	-0.227	-0.086	0.230	0.193
$BAF_{\Delta t}$ running average (EPA's Average Per-Period rate)	0.240	-0.243	-0.086	0.240	0.162
$BAF_{\Sigma T}$ approximation using BAF_t	0.329	-0.378	-0.120	0.344	0.317
$BAF_{\Sigma T}$ Cumulative Stock Difference-Based rate	0.334	-0.337	-0.112	0.344	0.326
T years	90	90	80	≈90	≈90

REFERENCES

Environmental Protection Agency. (2011, September). *Accounting Framework for Biogenic CO2 Emissions from Stationary Sources.* Office of Atmospheric Programs. Retrieved from http://www.epa.gov/climatechange/Downloads/ghgemissions/Biogenic-CO2-Accounting-Framework-Report-Sept-2011.pdf

Environmental Protection Agency Fact Sheet. (2011, September). *Fact Sheet*. Retrieved from Carbon Dioxide Emissions Associated with Bioenergy and Other Biogenic Sources: http://www.epa.gov/climatechange/ghgemissions/biogenic-emissions.html

EPA Office of Atmospheric Programs. (February 2015). *DRAFT Inventory of U.S. Greenhouse Gases and Sinks: 1990 - 2013.* Office of Air and Radiation. Retrieved from http://www.epa.gov/climatechange/pdfs/usinventoryreport/US-GHG-Inventory-2015-Main-Text.pdf

EPA Response to the SAB Panel Peer Review Advisory. (2015, February). *Response to the SAB Panel Peer Review Advisory*. Retrieved from SAB Biogenic Carbon Emissions Panel Meeting Webpage: http://yosemite.epa.gov/sab/SABPRODUCT.nsf/5295DAC6053510F285257DFD0075C181/$File/OAR+Response+to+SAB's+2012+Advice.pdf

IPCC. (2007). *Changes in Atmospheric Constituents and in Radiative Forcing. In: Climate Change 2007.* Cambridge, United Kingdom and New York, NY. Retrieved from http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-chapter2.pdf

James Neumann, I. E. (December 20, 2011). *Documentation of Peer Review Process for the FASOM-GHG Model for Climate Change Analysis.* Memo to Sara Ohrel, EPA Climate Change Division. Retrieved from http://www.epa.gov/climatechange/Downloads/EPAactivities/peerreview_FASOM.pdf

McCabe, J. G. (2014, November 19). *Addressing Biogenic Carbon Dioxide Emissions from Stationary Sources*. Retrieved from Memo to Air Divisoni Directors, Region 1 - 10: http://www.epa.gov/climatechange/downloads/Biogenic-CO2-Emissions-Memo-111914.pdf

Science Advisory Board, E.-S. 1.-0. (2012, September 28). *SAB Review of EPA's Accounting Framework for Biogenic CO2 Emissions from Stationary Sources*. Retrieved from SAB website : http://yosemite.epa.gov/sab/sabproduct.nsf/57B7A4F1987D7F7385257A87007977F6/$File/EPA-SAB-12-011-unsigned.pdf