8-27-15

EPA-SAB-12-xxx

The Honorable Gina McCarthy
Administrator
U.S. Environmental Protection Agency
1200 Pennsylvania Avenue, N.W.
Washington, D.C. 20460

Subject: SAB review of *Framework for Assessing Biogenic $CO_2$ Emissions from Stationary Sources* (2014)

Dear Administrator McCarthy:

The EPA Science Advisory Board (SAB) was asked by the EPA Office of Air and Radiation to review and comment on its *Framework for Assessing Biogenic $CO_2$ Emissions from Stationary Sources* (2014) ("2014 Framework"). The 2014 Framework considers the scientific and technical issues associated with accounting for emissions of carbon dioxide ($CO_2$) from biogenic feedstocks used at stationary sources.

The purpose of the 2014 Framework was to develop a method for calculating the adjustment, or Biogenic Accounting Factor (BAF) for biogenic feedstocks based on the biological carbon cycle effects associated with biogenic feedstock growth, harvest and processing. This mathematical adjustment to stack emissions is needed because of the unique ability of biogenic material to sequester $CO_2$ from the atmosphere, in biomass and soil, over relatively short time frames through the process of photosynthesis. It is also needed because of the emissions that are avoided when certain feedstocks are used for bioenergy (e.g. municipal solid waste) rather being disposed of in uncapped industrial landfills or left to decay on the ground (e.g. logging residuals). The BAF is an accounting term developed in the Framework to denote the offset to total emissions (mathematical adjustment) that reflects a biogenic feedstock's net carbon emissions after taking into account its sequestration of carbon, in biomass or soil, or avoided emissions.

The 2014 Framework is a revision of the 2011 Framework which the SAB reviewed and reported on in September 2012. We are pleased that the 2014 Framework incorporated the SAB's prior advice and we believe this has advanced the analytical foundation for making determinations about net contribution of biogenic feedstocks to the $CO_2$ in the atmosphere. Specifically, the 2014 Framework has incorporated the SAB's prior advice as follows:

- It has adopted an alternate fate approach (i.e. a counterfactual evaluation of what the net biogenic atmospheric contribution might have been if the feedstocks were not used for energy) to the collection and use of waste-derived feedstocks, including avoided methane ($CH_4$) emissions.
- It includes a robust discussion of the trade-offs inherent in the selection of a temporal scale;
- It has developed representative BAFs by feedstock and region in view of the data demands of a facility-specific BAF calculation;

- It includes a thorough review of existing approaches to addressing leakage, the phenomenon by which efforts to reduce emissions in one place affect market prices that shift emissions to another location; and most importantly:
- It has offered an approach to construct an anticipated baseline that allows assessment of the *additional* $CO_2$ emissions that might be attributed to biogenic feedstocks.

With respect to this last bullet, estimating *additionality*, i.e. the extent to which forest stocks would have been growing or declining over time in the absence of harvest for bioenergy, is essential, as it is the crux of the question at hand. EPA's reference point baseline approach (comparing the net change in carbon stocks between two points in time) does not provide an estimate of the *additional* emissions and the sequestration changes in response to biomass feedstock demand. Thus our 2012 report recommended an anticipated future baseline approach in which two carbon trajectories are compared: a "business as usual" trajectory of carbon emissions compared to a trajectory of carbon emissions in response to policy induced increased demand for biomass. The 2014 Framework applies this anticipated future baseline approach in some cases to answer the question of whether more or less carbon is stored in the system over time compared to what would have been stored in the absence of changes in biogenic feedstock use. However, the 2014 Framework has not chosen an anticipated baseline as its approach. It is simply one option.

The 2014 Framework did <u>not</u>, however, provide the policy context and implementation details the SAB previously requested. In fact, the lack of information in both Frameworks on EPA's policy context and menu of options made it much more difficult to fully evaluate these frameworks. As we stated in our 2012 report and we reiterate here: this SAB review would have been enhanced if the Agency offered a specific regulatory application that, among other things, would have provided explicit BAF calculations and defined its legal boundaries regarding upstream and downstream emissions. The 2014 Framework lacked concreteness and was written in a way that was too flexible, with too many possibilities. For instance, EPA describes a variety of possible BAF calculation options, including representative, customized, or hybrid; reference point or anticipated baseline; marginal, average, or augmented average; BAF per period, BAF average over time, or BAF cumulative; and undiscounted or discounted. EPA needs to make some decisions and offer justification for those choices. For proper scientific evaluation, the Framework needs to be applied in a specific policy context with specific BAF calculations and clearly defined boundaries for EPA's regulatory authority.

In some illustrative calculations, the 2014 Framework applied the anticipated future baseline approach to calculating a BAF. Our feedback on the revisions in the 2014 Framework centers around the metrics used to derive BAF. EPA's equations were based on emissions (fluxes) with some adjustment terms to account for mass escaping the system between the point of assessment and the point of emissions. We have proposed an alternative framework based on terrestrial carbon pools such as the live stores, dead stores, soil stores, that is more consistent with the principles of conservation of mass. Using carbon pool data because it has multiple advantages: it is typically inventoried and modeled; it can be aggregated and rearranged as needed or further subdivided; and it will follow conservation of mass and is subject to mass balance. Using a carbon pool framework, we have shown how to identify the time period (T) over which terrestrial effects occur in response to increased harvesting of biomass for energy. It is this time period that is the appropriate time scale for considering climate impacts from biogenic feedstocks.

Additionally, because it is the cumulative effect of all emissions over time that affects the climate, we have stated that a cumulative BAF of some type is scientifically appropriate.

Using the carbon stock framework, we have also identified an additional approach for calculating a cumulative BAF that attempts to account for the residence time of the additional emissions in the atmosphere relative to a BAU. The additional BAF approach (which we denote at $BAF_{\Sigma T}$) accumulates the annual differences in carbon stocks on the land *over time to time T*. By contrast, EPA's cumulative BAF in the 2014 Framework (which we denote as $BAF_T$) accounts for the difference in carbon stocks *at the end of the time horizon*. Both cumulative BAFs have pros and cons. The appropriate measure of BAF will depend on the scientific assessment of mechanisms by which changes in atmospheric carbon stock affect the climate. The effect of changes in long run equilibrium carbon stocks can be captured by $BAF_T$ while the transitional effects on climate may be better captured by $BAF_{\Sigma T}$. Climate and carbon cycle dynamics and uncertainties are important issues in considering the two cumulative BAFs.

In the hopes of further advances in biogenic carbon accounting, the SAB offers the following summary of our conclusions and recommendations.

1. For proper scientific evaluation of a biogenic carbon accounting approach, EPA should specify a policy context, propose specific BAF calculations and values, and specify its legal authorities over upstream and downstream emissions as well as the spatial boundaries for assessing impacts around a stationary facility. It is also important to have more clarity on underlying expectations about other prevailing land use management, renewable energy and carbon policies that could impact the choice of feedstocks and their production methods and thus the estimates of their BAF.

2. The appropriate time scale for considering climate impacts from biogenic feedstocks is the time period over which all terrestrial effects on the stock of carbon on the land occur in response to a policy induced shock in sustained demand for bioenergy.

3. A biogenic carbon accounting approach based on carbon stocks (terrestrial pools such as live, dead, soil, products, material lost in transport and waste) is preferred over an emissions (flux-based) approach because it comports with conventional carbon accounting, has well-defined boundaries and follows conservation of mass as well as mass balance.

4. A cumulative BAF metric is appropriate. An additional cumulative BAF approach is offered in the Appendices that takes into account the time path of changes in terrestrial carbon stocks *over time*, thus attempting to incorporate the residence time of carbon emissions. The appropriate cumulative approach for calculating BAF will depend on intertemporal trade-offs between short-term and long-term impacts of carbon emissions on the climate system for which there is uncertainty.

5. EPA should identify and evaluate its criteria for choosing a model and modeling features that affect BAF outcomes, e.g. assumptions, elasticities, structure and parameters and update and validate the model applied and incorporate the latest scientific knowledge.

6. BAF uncertainty should be evaluated.

The SAB appreciates the opportunity to provide advice on the 2014 Framework and looks forward to your response.

Sincerely,

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|---|---|
| Dr. Peter S. Thorne, Chair | Dr. Madhu Khanna, Chair |
| Science Advisory Board | SAB Biogenic Carbon Emissions Panel |

Enclosure

## NOTICE

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## Acronyms and Abbreviations

| | |
|---|---|
| AVOIDEMIT | Avoided Emissions |
| BAF | Biogenic Accounting Factor |
| BAU | Business As Usual |
| CH4 | Methane |
| CO2 | Carbon Dioxide |
| CO2e | Carbon Dioxide Equivalent |
| DOE | Department of Energy |
| EPA | Environmental Protection Agency |
| FASOM | Forestry and Agricultural Sector Optimization Model |
| GHG | Greenhouse Gas |
| GROW | Term in EPA's BAF equation representing net feedstock growth (or removals) |
| GWP | Global Warming Potential |
| N2O | Nitrous Oxide |
| SAB | Science Advisory Board |
| SITE_TNC | Term in EPA's BAF equation representing total net change in non-feedstock carbon pools on the feedstock production site due to land use management associated with feedstock production |
| USDA | U.S. Department of Agriculture |

# 1 EXECUTIVE SUMMARY

The EPA has returned to the SAB for its advice on a revised science-based framework for accounting for biogenic carbon emissions, which it defines as "$CO_2$ emissions related to the natural carbon cycle, as well as those resulting from the combustion, harvest, digestion, fermentation, decomposition, or processing of biologically based materials."[1] EPA's November 2014 *Framework for Assessing Biogenic $CO_2$ Emissions from Stationary Sources* (Environmental Protection Agency, 2014) is a sequel to its 2011 Framework (Environmental Protection Agency, 2011) which the SAB reviewed and reported on in September 2012 (Science Advisory Board, 2012). The goal of 2011 Framework was to provide the analytical foundation for making determinations about the estimated net atmospheric contribution of biogenic $CO_2$ emissions from the production, processing and use of biogenic feedstocks at stationary sources. The goal of the 2014 Framework is to evaluate biogenic $CO_2$ emissions from stationary sources that use biogenic feedstocks, given the ability of plants to remove $CO_2$ from the atmosphere through photosynthesis.

*Policy Context*

In its 2011-2012 review, the SAB was given a policy context for the biogenic $CO_2$ accounting framework. The SAB was told that the 2011 Framework was intended to guide the determination of $CO_2$ emissions from regulated stationary sources under the Clean Air Act, specifically those facilities receiving a prevention of significant deterioration ~~permit~~ (PSD) air permit that were required to conduct a best available control analysis (BACT) for $CO_2$ emissions. The question before the Agency and hence, the SAB, was whether and how to consider biogenic greenhouse gas (GHG) emissions in determining thresholds for permitting and decisions about BACT for $CO_2$ emissions from bioenergy.
The Agency has removed this policy context from its 2014 Framework and asked charge questions that seek general guidance on issues related to the choice of temporal, spatial and production scale for determining BAFs in a policy-neutral context. This change hampered the ability of the SAB to assess the suitability of the 2014 Framework for use as a science-based regulatory framework. While some of our responses are robust to policy and implementation, others would have been more specific had such details been provided. It would have also been useful to know more about the regulated entities that would be responsible for emissions associated with these effects. A broadly defined policy context, including policies for sustainable land management and biomass production established by other agencies, is also relevant for evaluating the impact of using biogenic feedstocks on the carbon cycle.

It would be helpful if EPA would state that the purpose of performing carbon accounting with the proposed Framework is to account for the emissions of greenhouse gases that alter the climate. Such a statement is crucial because this purpose must be explicit, not implicit, in the accounting framework so that limitations caused by inadequate inclusion of non-$CO_2$ gases such as $N_2O$ and $CH_4$ are recognized. The 2014 Framework mentions (page 10) that methane emissions from biogenic feedstocks are relatively small compared to those from other sources in the US and also illustrates the implications of accounting for $N_2O$ emissions for calculations of BAF. These non-$CO_2$ gases are particularly important for waste materials from landfills. This issue was addressed previously by the SAB (Science Advisory Board, 2012), however EPA's response did not provide an adequate rationale for not acknowledging the

[1] http://www.epa.gov/climatechange/ghgemissions/biogenic-emissions.html

importance of greenhouse gas emissions in the Framework, nor for the exclusion of consideration of $N_2O$ and limited consideration of $CH_4$ (Environmental Protection Agency, February 2015, p. 7). Even if an accounting framework is limited to $CO_2$ only, it is important to recognize and analyze the situations in which $CO_2$ emissions do not represent overall GHG emissions because of emissions of $N_2O$ and/or $CH_4$.

*Future Anticipated Baseline Approach*

To compare change in any system over time, there must be a baseline against which to assess changes so that two distinct scenarios can be compared. EPA's reference point baseline approach simply assesses the estimated net change in land-based biogenic $CO_2$ fluxes and/or carbon stocks between two points in time. In our 2012 SAB report, we stated that the reference point baseline approach is inadequate in cases where feedstocks accumulate over long time periods because it does not estimate the *additional* effect of a stationary facility's combustion of biomass on carbon emissions over time. We note that EPA has acknowledged this limitation in its 2014 Framework and conducted a future anticipated baseline analysis to ascertain the *additional* effect of increased biomass harvesting on emissions over time.

The SAB's 2012 advice on the anticipated baseline approach recognized, both then and now, that sophisticated modeling is needed to capture the interaction between the market, land use, investment decisions, emissions and ecosystem feedbacks and to construct a counter-factual scenario without bioenergy use. In the case of long rotation feedstocks, bioenergy demand can affect carbon stocks in many ways including the harvest ages of trees, the diversion of forest biomass from traditional forest product markets to bioenergy and rates of afforestation and deforestation. Estimating the net effect of these changes on carbon stocks requires a model that integrates market demand and supply conditions with biophysical conditions that determine growth of forest biomass, carbon sequestration and fluxes due to harvests and land use change and incorporates the spatial variability in these effects across the US.

Also consistent with our 2012 recommendations, EPA has now moved toward a "representative factor" approach that would include an assessment of the biogenic landscape attributes (type of feedstock, region where produced) as well as the process attributes, based on the stationary source process and types of biomass handling, that could be calculated using various spatial and temporal scales. EPA initially considered calculating a Biogenic Assessment Factor (BAF) for an individual stationary facility; however, the data needs for a facility-specific approach were daunting. This approach would require case-specific measurements and calculations of carbon stocks and fluxes and chain-of-custody carbon accounting while ignoring land use changes at a broader landscape level that may mitigate or exacerbate the effects within a "fuel-shed."

Although EPA's use of a representative factor approach is an advancement in its accounting methodology, its choices of representative factors for the 2014 Framework are of concern. In particular, the overly-broad feedstock categories (*e.g.*, roundwood in the Southeast, logging residues in the Pacific Northwest, and corn stover in the corn belt) reflect neither extant nor likely future variation in feedstock production or processing. This provides no incentives for implementation of best management practices in feedstock production, reduction of waste in storage and transport, nor incentive for innovation and improved efficiency at the stationary source itself. Likewise, it does not penalize feedstock producers who fail to meet the practices, standards, or efficiencies assumed in the calculation of the BAF. This lack of specificity represents an inherent limitation of the representative factor approach. As a rule, BAFs should be calculated at levels that reflect the diversity of production and processing practices available in a given region to either incentivize or penalize specific production strategies. This is also important in that it will guide investment decisions about feedstock choice, production methods and stationary facility siting.

Some of our 2012 statements bear repeating because they remain relevant. We recognized (then and now) the tradeoffs between simplicity, scientific rigor and policy effectiveness. We recognized the difficulty of undertaking an anticipated baseline approach and we said that practical considerations must weigh heavily in the agency's decision making. We said that any method that might be adopted should be subject to an evaluation of the costs of implementation and compliance against any savings in carbon emissions, and we maintain that caution in this Advisory.

In the 2014 Framework, EPA has offered simulations of future biophysical and economic conditions employing the Forestry and Agricultural Sector Optimization Model (FASOM) to determine the incremental greenhouse gas emissions of increased biomass feedstock demand compared to a "business as usual" scenario. EPA used FASOM-GHG for this complicated modelling with case studies based on 9 regions of the country. As we stated in 2012, for long rotation feedstocks, a regional scale (larger than the facility-specific scale) has the following advantages: it captures indirect (market) effects, it is less cumbersome than a chain-of-custody accounting; and it offers greater data availability. The EPA's case studies applied the future anticipated baseline approach on a regional basis to Southeastern roundwood, Corn Belt corn stover and Pacific Northwest logging residues, however none of its charge questions were feedstock or model-specific. Given that the carbon consequences of increased demand for biogenic feedstocks are likely to depend on the model selected to evaluate those consequences, a more robust discussion of the choice of modeling platform and its underlying assumptions and parameters would have been useful.

EPA posed very detailed charge questions to the SAB about its anticipated baseline modeling. Below, we have highlighted our responses to EPA's charge questions followed by our more general comments and recommendations.

*EPA's Charge Questions:*
*Part 1: Future Anticipated Baseline Approach and Temporal Scale*

Part I of EPA's charge questions pertain to the temporal scale and the anticipated baseline approach to calculating a BAF. The 2014 Framework is an improvement over the 2011 Framework with respect to the treatment of temporal issues. The 2014 Framework recognizes the intertemporal tradeoffs inherent in various timescales for examining emissions over time (Environmental Protection Agency, 2014, pp. B-1 to B-22).

With respect to selecting a temporal scale, the most important criterion is whether it captures effects over time, i.e. the terrestrial effects, both positive and negative, stemming from a change in the demand for biogenic feedstocks. Similar to EPA's concept of an "emissions horizon", we recommend defining the time horizon as the period of time over which all terrestrial effects occur, both positive and negative. The temporal scale for positive and negative terrestrial effects may differ across feedstocks but the longest of these, as measured for any given feedstock production system, should set the end point of the temporal scale used for all feedstocks. We do not support changing the temporal scale to fit a policy horizon (EPA's so-called "assessment horizon"); rather the time scale should be chosen to capture all effects. A long time horizon should not be chosen simply as a means of diluting the short-term effects of policy decisions that may or may not be reversed or changed, however.

We are proposing an alternative framework based on the differences in carbon stocks on the land in contrast to EPA's framework which is based on carbon emissions. Our proposed alternative framework in Appendix A: Alternative Framework Based on Carbon Pools offers a prototype equation with terms for the ~~net change in~~ live stores, the ~~net change in~~ dead stores, the ~~net change in~~ soil stores, the ~~net change in~~ product stores and the ~~net change in~~ waste stores. A key feature of using land carbon stocks is that all terms can be readily aggregated or disaggregated and are still subject to mass balance. The new stock-based framework presented in Appendix A would be scale and process invariant as it could be used for a stand, plot, fuel shed, or region. It would comport with the current conventions in carbon accounting which essentially use input-output tracking of carbon throughout the system with well-defined boundaries. Using a carbon pool framework, we have shown how to identify the time period (T) over which terrestrial effects occur in response to increased harvesting of biomass for energy. It is this time period that is the appropriate time scale for considering climate impacts from biogenic feedstocks.

Since the approach used to calculate a BAF should reflect the effect of carbon emissions on the climate, we support a BAF metric that is based on cumulative changes in carbon stocks over a time horizon rather than a BAF based on per period changes in emissions. EPA has offered one such cumulative BAF metric that is based on cumulative carbon changes ~~*at a point in time*~~. We prefer a cumulative metric over any per-period BAF or other short-run calculations.

In the Appendices to this report, we offer for EPA's consideration a modification to EPA's cumulative BAF approach that takes account of "residence time" of $CO_2$ emissions, ~~i.e. the length of time emissions are resident in the atmosphere during the selected time horizon.~~ To take account of residence time, this modification would accumulate the annual differences in carbon stocks on the land *during the entire time horizon*. In contrast, EPA's approach to a cumulative BAF (which we designate as $BAF_T$) would simply account for the difference in carbon stocks *at a single point in time at the end of the selected time horizon*. By cumulating annual differences across the entire projection period, this modified BAF formula (which we designate as $BAF_{\sum T}$ ) would yield something like the notion of "ton-years" to account for differences in carbon stocks *each year*. By taking the time path and residence times of emissions into account, we offer for EPA's consideration a measure that provides an indicator of the contribution of biogenic emissions to radiative forcing or the overall balance between incoming solar radiation and energy radiated back to space during the selected time horizon. Both cumulative BAFs have pros and cons. The appropriate measure of BAF will depend on the scientific assessment of mechanisms by which changes in atmospheric carbon stock affect the climate. The effect of changes in long run equilibrium carbon stocks can be captured by $BAF_T$ while the transitional effects on climate may be better captured by $BAF_{\sum T}$. Climate and carbon cycle dynamics and uncertainties are important issues in considering the two cumulative BAFs.

*Part II: Scales of Biomass Use When Applying Future Anticipated Baseline Approach*

Part II of EPA's charge questions was entirely devoted to very technical considerations concerning how to select model perturbations in biomass demand ("shocks") for the anticipated future baseline simulations to estimate the net atmospheric contribution of biogenic CO2 emissions. Some of these questions were difficult to answer in the absence of information about programmatic goals, legal boundaries and implementation details. Some questions in this section would have been better framed by specifying policy scenarios that may either have an explicitly stated scale of biomass demand changes or that could be used to simulate a scale of demand for biomass. Noting these limitations, our responses are highlighted below.

EPA asked for our general recommendations on the scale of demand change that should be used in a model for the future anticipated baseline approach. Typically, biomass demand changes should be modelled in response to particular policy scenarios like the Clean Power Plan or multiple policies likely to be implemented simultaneously that create incentives to use biogenic feedstocks such as the Renewable Portfolio Standard, the Renewable Fuel Standard etc. One approach would be to model the aggregate demand for biomass and the feedstock and region specific demands for biomass likely to be generated by a specific policy (or policy mix). Alternatively, the aggregate demand for biomass could be specified in a policy neutral context at various incremental levels, e.g. 1 million tons, 2 million tons, 3 million tons and in each case the feedstock-specific and region-specific demands and corresponding values of the Biogenic Accounting Factor could be determined. In general, the BAF should be estimated for the last unit demanded for a feedstock; the size of that last unit should be selected using a data-driven approach to be large enough to result in a significant change in the BAF (at the one decimal level). Demand changes should be bounded, of course, by historical data on resource use and be guided by observed information on current and planned expansions to facilities using biogenic feedstocks to be consistent with reality. Modeling exercises could also be undertaken to determine BAF thresholds for different levels of the size of the total change in demand.

For any given change in total demand for biomass, the demand for individual feedstocks should be determined endogenously so that it is economically viable and constrained by the joint production function. A sensitivity analysis to examine the sensitivity of this mix ex-post (after assigning BAFs to feedstocks) should be conducted to determine the robustness of the BAFs assigned to specific feedstocks.

A retrospective evaluation of the observed level of demand and mix of feedstocks would allow revisions to EPA's estimates of feedstock demand changes based on updated data. To evaluate the performance of a BAF retrospectively, quantities of biomass feedstock used by stationary sources could be updated and predictions about biomass demand at stationary facilities could be tested against actual outcomes. While a BAF may be calculated with a 100 year time horizon, assuming that forest and land management practices will be maintained over that period, they need to be updated periodically to incorporate changes in market conditions, land use and land cover and policies over time.

*Other Issues:*

*Alternate Fate Approach for Waste-Derived Feedstocks*

In 2012, the SAB said that EPA should consider the alternate fate of waste-derived feedstocks diverted from the waste stream, whether they might decompose over a long period of time, whether they would be deposited in anaerobic landfills, whether they are diverted from recycling and reuse, etc. In the 2014 Framework, EPA has conducted extensive alternate fate calculations in Appendix N; however, EPA drew a narrow boundary around point source emissions and neglected other significant considerations that affect the greenhouse gas footprint of alternative municipal solid waste (MSW) management alternatives. Specifically, the EPA neglected to quantify the benefits of electrical energy recovery from both landfills and combustion, and neglected to quantify carbon storage associated with landfills. Moreover, the landfill baseline that was selected is inconsistent with regulatory practice. Under the Clean Air Act New Source Performance Standards, EPA requires landfills above a certain size to, at a minimum, collect and control (e.g., flare) landfill gas. This standard was written to apply to more than half of the waste disposed in landfills. As such, a baseline of direct venting is misleading. Finally, some states regulate gas collection more strictly than the federal standard and this too must be recognized. The relative rankings in the 2014 Framework would change considerably if energy recovery were considered (Environmental Protection Agency, 2014, pp. N-9). The 2014 Framework clearly includes methane associated with municipal solid waste feedstocks, while neglecting to quantify the benefits of electrical energy recovery from both landfills and combustion, and neglecting to quantify carbon storage associated with landfills.

*Choice of Model*

EPA did not ask for feedback on its choice of model or any general criteria for choosing a model but given that the choice of model can determine results, we think this was an oversight. It should be pointed out that FASOM is an intertemporal optimization model that assumes perfect foresight. Economic agents are assumed to be forward-looking and their expectations about future market conditions drive management decisions in the present. Because of this assumption, landowners and firms automatically engage in “anticipatory planting and management” in response to expected changes in biomass demand. In Appendix J, EPA provided a detailed discussion of models in general and FASOM in particular, but there was no discussion of how FASOM’s assumption of anticipatory planting affected the estimates of biogenic accounting factors (BAFs). For Southeast roundwood, FASOM projected that an increase in the demand for Southeastern roundwood would result in a net increase in tree planting and investments. The increased investments, in turn, provide additional tree growth and carbon sequestration offsetting the emissions associated with the increased harvests. The result for the FASOM model in the southeast is a reduction in biogenic CO2 emissions relative to a “business as usual” scenario. This result is somewhat counterintuitive so it is important to understand how FASOM’s assumptions translated increased biomass demand into increased forest investments. As a deterministic, dynamic simulation model, FASOM assumes that although individual agents do not operate with perfect foresight nor do they know with certainty, all relevant information for all future years, in the aggregate the collective decision is correct. Therefore, since expectations about future prices drive investment behavior, this assumption implies that any increase (decrease) in demand for biomass feedstocks automatically translates into increased (decreased) investments that perfectly satisfy that demand in the future. This assumption virtually guarantees a particular outcome e.g., a low BAF for feedstocks for long time horizons where demand is expected to increase through time because investment behavior will always compensate for any changes in the removal rates of carbon from the land. This “anticipatory planting” assumption should be examined along with other assumptions in the FASOM model, such as feedstock yield functions, rates of growth of yields and their soil carbon effects (particularly for non-forest feedstocks).

The model selected for estimating BAFs should be validated to examine how closely it predicts the observed economic and land use reality. To ensure that the projections incorporate the best available science on biogenic feedstocks, the model should be updated with the latest scientific information on biophysical and biogeochemical properties of these feedstocks.

*Summary of Conclusions and Recommendations:*

EPA's 2014 Framework has advanced biogenic carbon accounting and offered improvements over its 2011 Framework. As captured in the 2014 Framework, the anticipated baseline approach to calculating BAFs, while subject to implementation difficulties and all the uncertainties associated with modeling the future, represents an advance in biogenic carbon accounting. In the hopes of further advances in biogenic carbon accounting, the SAB offers the following summary of our conclusions and recommendations.

1. For proper scientific evaluation of a biogenic carbon accounting approach, EPA should specify a policy context, propose specific BAF calculations and values, and specify its legal authorities over upstream and downstream emissions as well as the spatial boundaries for assessing impacts around a stationary facility. It is also important to have more clarity on underlying expectations about other prevailing land use management, renewable energy and carbon policies that could impact the choice of feedstocks and their production methods and thus the estimates of their BAF.

2. The appropriate time scale for considering climate impacts from biogenic feedstocks is the time period over which all terrestrial effects on the stock of carbon on the land occur in response to a policy induced shock in sustained demand for bioenergy.

3. A biogenic carbon accounting approach based on carbon stocks (terrestrial pools such as live, dead, soil, products, material lost in transport and waste) is preferred over an emissions (flux-based) approach because it comports with conventional carbon accounting, has well-defined boundaries and follows conservation of mass as well as mass balance.

4. A cumulative BAF metric is appropriate. An additional cumulative BAF approach is offered in the Appendices that takes into account the time path of changes in terrestrial carbon stocks *over time*, thus attempting to incorporate the residence time of carbon emissions. The appropriate cumulative approach for calculating BAF will depend on intertemporal trade-offs between short-term and long-term impacts of carbon emissions on the climate system for which there is uncertainty.

5. EPA should identify and evaluate its criteria for choosing a model and modeling features that affect BAF outcomes, e.g. assumptions, elasticities, structure and parameters and update and validate the model applied and incorporate the latest scientific knowledge.

6. BAF uncertainty should be evaluated.

# 2 INTRODUCTION

EPA's Science Advisory Board (SAB) was asked by the EPA Office of Air and Radiation to review and comment on its Framework for Assessing Biogenic CO2 Emissions from Stationary Sources (2014). The 2014 Framework considers the scientific and technical issues associated with accounting for emissions of carbon dioxide (CO2) from biogenic feedstocks used at stationary sources.

The purpose of the 2014 Framework was to develop a method for calculating the adjustment, or Biogenic Accounting Factor (BAF) for biogenic feedstocks based on the biological carbon cycle effects associated with biogenic feedstock growth, harvest and processing. This mathematical adjustment to stack emissions is needed because of the unique ability of biogenic material to sequester CO2 from the atmosphere, in biomass and soil, over relatively short time frames through the process of photosynthesis. It is also needed because of the emissions that are avoided when certain feedstocks are used for bioenergy (e.g. municipal solid waste) rather being disposed of in uncapped industrial landfills or left to decay on the ground (e.g. logging residuals). The BAF is an accounting term developed in the Framework to denote the offset to total emissions (mathematical adjustment) that reflects a biogenic feedstock's net carbon emissions after taking into account its sequestration of carbon, in biomass or soil, or avoided emissions.

The 2014 Framework is a revision of the 2011 Framework which the SAB reviewed and reported on in September 2012. To conduct the review, the SAB Staff Office reconstituted the Biogenic Carbon Emissions Panel with its experts in forestry, agriculture, greenhouse gas measurement and inventories, land use economics, ecology, climate change and engineering. Regrettably, three former panelists could not participate (Drs. Richard Birdsey, Richard Nelson and Lydia Olander). The SAB Panel's remaining 15 members covered the breadth of expertise needed for this review. A face-to-face meeting was held in Washington, D.C. on March 25 – 26, 2015 followed by four teleconferences over the summer of 2015 to draft and finalize its report. During the course of deliberations, the SAB Panel considered written and oral comments from members of the public.

# 3 RESPONSES TO EPA'S CHARGE QUESTIONS

## 3.1 Temporal Scale for Biogenic Accounting

*Charge Question 1: What criteria could be used when considering different temporal scales and the tradeoffs in choosing between them in the context of assessing the net atmospheric contribution of biogenic CO2 emissions from the production, processing, and use of biogenic material at stationary sources using a future anticipated baseline?*

The selection of a temporal scale for biogenic carbon accounting should be based on the time horizon over which effects are expected to occur. Here we refer to the effects, both positive and negative, of a change in the demand for bioenergy. Selection of the temporal scale should include consideration of growth and harvest cycles, short- and long-term soil carbon changes, and direct and indirect effects on the land. These effects may work on different temporal scales across feedstocks, but the longest of these as measured for any feedstock production system should set the end point of the temporal scale used for biogenic carbon accounting for all feedstocks.

To fully account for all positive and negative terrestrial effects over time, we recommend using the "emissions horizon" as described by the 2014 Framework. As defined by EPA, this "emissions horizon" is the period of time during which the carbon fluxes resulting from actions taking place today actually occur …" (Environmental Protection Agency, 2014, pp. B-3). In the context of an anticipated baseline approach, this emissions horizon would be the length of time it would take for the effect of increased demand for a feedstock on the carbon cycle to reach a state in which the difference in carbon stocks between the policy case and the reference case is no longer changing or if the difference is approaching an asymptote. Defining the emissions horizon to be long enough to achieve a state where the difference in carbon stocks between the policy case and the reference case stabilizes or approaches stabilization will ensure that all positive and negative changes in carbon stocks attributable to increased use of a bioenergy feedstock have been accounted for to the extent tractable. This time horizon should be standardized by selecting the longest time period among the various feedstock horizons and applying it to all feedstocks.

a. *Should the temporal scale for computing biogenic assessment factors vary by policy (e.g., near-term policies with a 10-15 year policy horizon vs mid-term policies or goals with a 30-50 year policy horizon vs long-term climate goals with a 100+ year time horizon), feedstocks (e.g., long rotation vs annual/short-rotation feedstocks), landscape conditions, and/or other metrics? It is important to acknowledge that if temporal scales vary by policy, feedstock or landscape conditions, or other factors, it may restrict the ability to compare estimates/results across different policies or different feedstock types, or to evaluate the effects across all feedstock groups simultaneously.*

As discussed above, the temporal scale should be chosen to capture all effects on carbon stocks, both direct and indirect – thus it should not vary by policy or landscape conditions.

i. *If temporal scales for computing biogenic assessment factors vary by policy, how should emissions that are covered by multiple policies be treated (e.g., emissions may be covered both by a short-term policy, and a long-term national emissions goal)? What goals/criteria might support choices between shorter and longer temporal scales?*

Temporal scales not vary by policy. They should, instead, be chosen to capture all effects on the carbon stocks. The 2014 Framework refers to an assessment horizon which may be specified by a particular policy. We recommend using the broader definition of the emissions horizon rather than the assessment horizon described in the 2014 Framework.

ii. *Similarly, if temporal scales vary by feedstock or landscape conditions, what goals/criteria might support choices between shorter and longer temporal scales for these metrics?*

Please see the overall response to Question 1 above.

iii. *Would the criteria for considering different temporal scales and the related tradeoffs differ when generating policy neutral default biogenic assessment factors versus crafting policy specific biogenic assessment factors?*

No, the criteria for selecting a temporal scale should simply be based on the period of time over which effects are expected to occur.

b. *Should the consideration of the effects of a policy with a certain end date (policy horizon) only include emissions that occur within that specific temporal scale or should it consider emissions that occur due to changes that were made during the policy horizon but continue on past that end date (emissions horizon)?*

No, based on the same principle that all effects should be considered (both short-term and long-term, both direct and indirect) during the emissions horizon, the effects of a policy should not be limited to an arbitrary policy horizon that may be shorter than the emissions horizon. It should include all changes in carbon stocks that occur during the emissions horizon.

c. *Should calculation of the biogenic assessment factor include all future fluxes into one number applied at time of combustion (cumulative – or apply an emission factor only once), or should there be a default biogenic assessment schedule of emissions to be accounted for in the period in which they occur (marginal – apply emission factor each year reflecting current and past biomass usage)?*

Cumulating all effects of the use of a biogenic feedstocks over a time horizon is preferred to a marginal or instantaneous ("per period") BAF. (For the purposes of answering this question, we are interpreting "marginal" to mean "annual" or "per period" so as to distinguish it from the meaning of "marginal" that typically refers to the last unit of emissions or the additional effect of the last unit).

We note that EPA's cumulative BAF metric is based on changes in carbon stocks at any single point in time. There are other approaches to a cumulative BAF metric. One such approach is based on the accumulation of annual differences in carbon *stocks* on the land over the time horizon rather than annual differences in *emissions (fluxes)*. The rationale for this follows.

Carbon accounting for biogenic emissions can either be framed using differences in carbon in the atmosphere or using differences in carbon stores on the land and in water. Since carbon that is not stored on the land and water is emitted to the atmosphere, conservation of mass dictates that any carbon taken from the land and water (through increased harvests in the policy case) will result in equivalent increases of carbon in the atmosphere. Thus these approaches are compatible. However, both approaches must account for changes that occur due to the boundaries of the analysis, such as import and export of biogenic feedstocks, use of feedstocks in ways that fall outside the scope of the policy, etc.

The use of biogenic feedstocks can affect the time sequence of emissions in the policy case relative to the time sequence of emissions in the reference case. These each affect the time sequence of terrestrial and aquatic carbon stocks in both cases. Moreover, near term removal of biomass can have feedback effects on biomass growth potential in the future and affect the entire trajectory of carbon on the land and water in the future. The atmospheric effects of biogenic feedstock removal may play out over many years to many decades and it is the sequence of increased biogenic emissions collectively which determine the time path of carbon changes on the land and water.

At any point in time, over a projection period, the effect on the atmosphere (what the atmosphere sees) from the sequence of biogenic emissions will be the difference in carbon stocks on the land and water. Considering all of these differences in carbon stocks at each point in time and not just the difference in carbon stocks at a single point in time is a way to capture the full effect of the use of biogenic feedstocks over a time period. Denoted as $BAF_{\sum T}$, this modification to EPA's approach accounts for the residence time of emissions which is an integral part of radiative forcing. For each year that a ton of $CO_2$ emissions resides in the atmosphere, it contributes to radiative forcing or the difference between incoming sunlight absorbed by the Earth and energy radiated back into space. As explained further below, this modification to the BAF formula, as explained further below, would yield something like the notion of "ton-years" to account for differences in carbon stocks *each year*.

As noted in the 2014 Framework, conceptually, we seek to answer the following question:

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

To answer this question, Appendix B offers an alternative framework based on differences in carbon stocks between a policy case and a reference case rather than differences in carbon fluxes. A key feature of using land carbon stocks is that all terms can be readily aggregated or disaggregated and are still subject to mass balance.

We define:

$$NBE_{\Sigma T} = \sum_{t=0}^{T} (TC_{Reference} - TC_{Policy})$$

Where:
$TC^{i}_{policy}(t)$ = the total stock of land carbon in the policy case in year *t* with increased demand for a biogenic feedstock; and
$TC_{Reference}(t)$ = the total stock of land carbon in the reference case in year *t*.

While our anticipated baseline based approach is consistent with EPA's, $BAF_{\Sigma T}$ would accumulate the annual differences in carbon stocks on the land [which ~~represent the accumulated annual differences of $CO_2$ in in the atmosphere~~] ~~over the projection period.~~ To do this, NBE and PGE would reflect the differences in carbon stocks between the policy scenario and the reference scenario. We can interpret $NBE_{\Sigma T}$ as the sum of the annual differences in carbon stock in the atmosphere from time t=0 to T associated with biogenic feedstock use. This term is the numerator of the $BAF_{\Sigma T}$ ratio.

The denominator of the $BAF_{\Sigma T}$ formula should also be measured in terms of the difference in carbon stocks in the atmosphere due to the use of the biogenic carbon at the stationary facility. Specifically, for the denominator we first define ~~$PGE_{\Sigma T}$~~ to be the sum of annual emissions from a biogenic feedstock from time 0 up through time t, where each annual emission is denoted by $PGE_{\Delta t}$. This represents the gross amount of carbon stock in the atmosphere at time t due to stationary source emissions.

The accumulated annual amounts of gross emissions from time 0 to the time horizon *T* is represented by

$$PGE_{\Sigma T} = \sum_{t=0}^{T} PGE_t$$

We now define $BAF_{\Sigma t} = \frac{NBE_{\Sigma T}}{PGE_{\Sigma T}}$ for a given time horizon T.

The numerator represents the accumulated annual differences in the carbon stock over a total period of time T between the policy case (with increased demand for biogenic carbon) and the counterfactual reference baseline. It also represents the corresponding difference in C the atmosphere sees over the projection period. This ratio takes into account the effect on the atmosphere of periods of time when differences in carbon stocks may be large as well as periods when they may be small.

After subtracting the policy case from the reference case, a loss in carbon stocks in the policy case relative to the reference case would lead to a positive sign for $NBE_{\Sigma T}$. Conversely a gain in carbon stocks compared to the reference case would lead to a negative sign. If this approach for calculating the BAF is utilized for long rotation feedstocks, it should also be used for all other feedstocks to maintain comparability.

We illustrate this $BAF_{\Sigma T}$ value graphically in Appendix C and Appendix D in different cases. These cases provide examples with carbon stores in the reference case being larger or smaller than the policy case over the entire time horizon. We also provide examples where total carbon stocks reach a new steady state as well as scenarios in which equilibrium is not reached.

We now clarify how this proposed approach differs from the approaches presented in the 2014 Framework which describes two different ways to calculate the BAF: a cumulative BAF and a per-period BAF (Environmental Protection Agency, 2014, pp. L-9). EPA's cumulative BAF in the 2014 Framework is based on the difference in emissions between the reference case and the policy case as follows:

$$NBE_t = \sum_{t=0}^{T} \Delta TC_{Reference}(t) - \Delta TC_{Policy}(t) = \mathrm{TC}_{Reference}(T) - TC_{Policy}(T)$$

where $\Delta TC$ is the change in carbon stocks at time *t* relative to *t-1* and equal to the net emissions at time *t*. Here $NBE_t$ is the NBE at a point in time and equals the sum of the annual changes in emissions. Mathematically, $NBE_t$ adds up to the difference in stocks at time t. This cumulative BAF as defined in the 2014 Framework as:

$BAF_t = NBE_t/PGE_t$ where $PGE_t$ is gross emissions at time *t*. Note this is different from the our proposed alternative definition of PGE given above in which it is the accumulation of annual gross emissions each year *t=0,…T*. EPA's cumulative BAF is also shown graphically in Appendix C and referred to as $BAF_t$. If the time period at which the BAF is measured is *t=T* then $BAF_T = NBE_T/PGE_T$

The per-period BAF in the 2014 Framework is based on the change in emissions at a point in time.

$$\Delta TC_{Reference}(t) - \Delta TC_{Policy}(t)$$

$$BAF_{\Delta t} = \frac{\Delta TC_{Reference}(t) - \Delta TC_{Policy}(t)}{PGE_{\Delta t}}$$

This is shown graphically in Appendix C as well. Additionally, averages of the per-period BAF at each point in time as well as a moving average of the per-period BAF is also computed and included in the graphs for comparison.

As shown in Appendix C, all BAF values decline as T increases and in some cases may not stabilize as T increases. Thus choice of time scale is critical in defining the value of the BAF. In the $BAF_{\Sigma T}$ framework, a general rule is that one can determine T to be when the NBEΔt asymptotes. In many cases, NBEΔt will asymptote at zero. When there is random variation from year to year, it will average zero. When there are changes in the landscapes inherent productivity (e.g., NPP) in the policy case that continue longer than the "assessment" window, then it is possible for the NBEΔt to asymptote at a positive or negative value (see cases 4 and 5 in Appendix C). The amount of carbon gained or lost in the policy scenario relative to the reference scenario is substantially but not fully partially reflected at time T. However, there can be a continued gain or loss of carbon because the policy case could change inherent productivity relative to the reference case. The effect of the policy could be more or less depending on external changes in the environment. There is no scientific way to determine after this point (when NBEΔt asymptotes at a non zero value) the degree to which the policy case or the external changes in the environment are most responsible for the changes after time T. For the non zero cases EPA will need to make a policy decision whether the BAF used accounts for just the period up to T or extends beyond that period to include the interaction of environmental changes and the policy scenario. Another consideration is that the error bounds on predictions of NBE$\Delta$t will increase with t (indicated by sensitivity tests) and could eventually include zero. This would indicate we would no longer accept the hypothesis that there is a change in difference in land C between the policy and reference cases. This uncertainty could be considered in identifying when NBE$\Delta$t is zero.

The examples in Appendix C also show that these different measures of BAF can lead to widely different values for any particular case. For the range of examples we present, $BAF_{\Sigma T}$ is generally larger in absolute terms than the cumulative emission based BAF and the Per-Period BAF in cases where the stock of carbon in the reference case is higher than that in the policy case.

There are at least three uses of a carbon accounting metric that uses an approach similar to $BAF_{\Sigma T}$ which equally weights yearly differences in carbon stocks over time to measure impact on the atmosphere. The California Air Resources Board in their Compliance Offset Protocol for U.S. Forest Projects calculates credit for carbon stored in harvested wood products as the equally weighted (average) annual carbon storage over a 100 year period (California Air Resources Board, 2014). This is same method used for $BAF_{\Sigma T}$ which calculates the effect of biogenic emissions as the equally weighted annual carbon not stored over a time, from t=0 to T. In addition, U.S. Department of Agriculture guidelines for agricultural and forest entity reporting of greenhouse gas sources and sinks in managed forests also gives credit for carbon stored in harvested wood products using this method (Hoover, et al., 2014). The U.S. Department of Agriculture guidelines also use equal time weighting of carbon stored on the land to credit carbon storage in biomass crops grown on agricultural land (Ogle, 2014).

With either approach to evaluating BAF, caution is advised with projections into the future. For example, a BAF calculation is based on modeling that implicitly assumes feedstock regrowth following an assumed rotation length and that carbon sequestered in soils would continue indefinitely. Given the uncertainty about the maintenance of our forests and agricultural land use policies and practices, the BAF needs to be updated periodically to reflect latest data and trends and a one-time cumulative BAF may not remain an accurate representation of reality over time. Therefore the model used to determine the BAF needs to be updated and validated periodically to ensure that the underlying information on which it is based is still valid. Additionally, the likelihood of a cumulative BAF being realistic also depends on other policies in place that encourage or, at least, do not discourage long term sustainable land and forest management.

A shifting projection of the reference baseline that includes a historical period could be used to reset the baseline periodically based on re-measuring carbon stocks on the landscape, based on existing inventory programs, effectively improving the accuracy of the baseline over time. Future changes in growth-to-harvest ratios could be used to inform the model assumptions and modify the BAF that would be applicable going forward. This would create long term incentives for sustainable management of land resources. In any accounting framework that assumes future regeneration and regrowth, it is important to continually test this assumption against actual data as it becomes available.

*d. What considerations could be useful when evaluating the performance of a future anticipated baseline application on a retrospective basis (e.g., looking at the future anticipated baseline emissions estimates versus actual emissions ex post), particularly if evaluating potential implications for/revisions of the future anticipated baseline and alternative scenarios going forward?*

There are ~~two~~ key considerations in evaluating the performance of a future anticipated baseline application on a retrospective basis:

(a) how well the model predicts the level of feedstock specific demand in each region;
(b) how well the model predicts land use changes, e.g. afforestation and conversion of land to dedicated energy crops; and
(c) forest carbon changes, both the level and composition.

A retrospective analysis would compare these predictions to the observed reality. To the extent that there are differences between model predictions and observed reality it will be important to examine key parameters, functional forms and assumptions of the model. The goal of an ex post evaluation would be to make adjustments to the key parameters, functional forms and assumptions that can be improved with hindsight, thus improving the ability of the model to predict the impact of increased demand for biomass for the future. Beyond economic dynamics, forest carbon dynamics should also be examined including not only the extensive margin (land use), but also changes in management intensity, forest rotations and other forest dynamics.

A key assumption to revisit retrospectively will be the role of expectations about the policy driven demand for biomass for the behavioral responses induced by it. The FASOM model used for the analysis in the 2014 Framework has advantages including national scope with spatial detail and endogenous determination of agricultural and forest–based feedstocks. By incorporating a deterministic future, rational expectations and optimal adjustment, however, the projected future would likely differ from actual outcomes where agents may make harvest and subsequent planting decisions in response to short-term market cycles given an uncertain future. It seems likely that the estimated BAF will be sensitive to assumptions about expectations and how agents respond to them. It will be important to examine the extent to which observed responses, particularly those related to anticipatory planting of forests to meet future demand for biomass are consistent with reality; if wide divergences are observed that cannot be corrected using the FASOM modeling framework then alternative models that incorporate market and biological dynamics but assume more myopic decision makers should be considered. The sensitivity of the estimated BAF to various assumptions including those related to expectations and how agents respond to them and the scale of demand should also be examined. The existence of threshold effects on BAF values could be examined to determine which assumptions in particular lead to meaningful changes in the BAF value and require closer scrutiny.

## 3.2 Scales of Biomass Use

*Charge Question 2: What is/are the appropriate scale(s) of biogenic feedstock demand changes for evaluation of the extent to which the production, processing, and use of biogenic material at stationary sources results in a net atmospheric contribution of biogenic CO2 emissions using a future anticipated baseline approach? In the absence of a specific policy to model/emulate, are there general recommendations for what a representative scale of demand shock could be?*

a. *Should the shock reflect a small incremental increase in use of the feedstock to reflect the marginal impact, or a large increase to reflect the average effect of all users?*
b. *What should the general increment of the shock be? Should it be specified in tons, or as a percentage increase?*

We have lumped questions 2a – b together because they relate to the size of the simulated "shock" in biomass feedstock demand.

If EPA's goal is to obtain a region specific BAF for a feedstock, it will be necessary to project region-specific, feedstock-specific demand for biomass. Since the BAF for a feedstock could differ depending on the method of production (for example, the soil carbon implications of corn stover will depend on the type of tillage practice used and the amount of residue harvested), it will be appropriate to have the BAF for a feedstock in a region vary by feedstock production method. To the extent that BAFs depend on technology and emissions control regulations at a stationary facility in a region, they could be made technology specific.

Instead of setting the quantity of demand for each feedstock in each region exogenously (as questions 2a and 2b suggest), it would be preferable to use a model to simulate the impact of a given policy-induced level of aggregate (national-level) demand for biomass to determine the mix of feedstocks and the quantity of each feedstock likely to be demanded, the methods of producing it and using it in a representative facility in each region in equilibrium. The (policy case) equilibrium level of each feedstock in each region will provide the economically viable mix and level of demand for each feedstock in each region that will meet that aggregate demand. To the extent that feedstock production methods and technology choices by a stationary facility are guided by policies, these policies should be incorporated in the economic model used to determine feedstock mix both in the reference case and the policy case. It is important to note that this will result in multiple BAFs reflecting the diversity in production and use in a given region could be calculated for a given feedstock (e.g., roundwood or corn stover), rather than a single BAF, reflecting diversity as well as carbon effects above and below a range to provide incentive for exceeding common BAFs or penalties for failing to meet them.

The carbon implications of using feedstocks in each region to get region-specific, feedstock-specific BAFs can be determined either by (1) applying the equilibrium quantity of demand ~~for feedstocks~~ in a region determined above as the change in demand for those feedstocks alone relative to the reference case and analyzing the carbon implications in the home region and other regions to obtain average BAFs across all users for those feedstocks for that region or (2) increasing demand ~~for feedstocks~~ in a region by a marginal (incremental) level relative to the equilibrium (policy case) level for that region determined above and simulating its effect on emissions to isolate the effect of the last unit of those feedstocks on carbon emissions compared to the policy case while keeping total national demand for all other feedstocks at the equilibrium (policy case) level.

The second estimation method above would provide BAFs based on the impact of the marginal increase in demand for feedstocks in a region on carbon emissions while taking into account its effect on all other regions. BAFs calculated for the marginal impact of the last ton could be used to provide the appropriate signal of the carbon impact of using one more unit of that feedstock in a region to a facility in that region.

Since there is uncertainty about the aggregate demand for biomass likely to emerge at the national level due to a policy, this analysis could be conducted for various hypothetical levels of aggregate demand. In this manner, BAFs for feedstocks for each region could be obtained. This approach could be used to determine the sensitivity of the feedstock-specific BAFs to the level and time-path of the change in aggregate demand for biomass relative to the reference case.

*c. Should the shock be from a business as usual baseline, or from a baseline that includes increased usage of the feedstock (i.e., for a marginal shock, should it be the marginal impact of the first ton, or the marginal impact of something approximating the last ton)?*

Since the goal is to quantify the carbon implications of a future scenario with demand for biogenic feedstock use relative to that without demand for biogenic feedstock use, the reference case should be one with no/limited demand for biomass which would characterize the situation before any policy that creates incentives for demanding bioenergy. Projection of future demand for biomass due to a policy could specify an increase in aggregate demand for bioenergy in the next 5-10 years based on an assessment of announced/anticipated facility capacity for consuming biogenic feedstocks and evaluate its BAF implications for specific feedstocks assuming that aggregate demand remains fixed at that level over a time horizon T after that. This would imply that the feedstock and region specific BAFs will need to be updated periodically to correspond to different levels of aggregate demand for biomass and to converge to the reality observed as the feedstock market develops.

In addition to selecting the aggregate level of demand for biogenic energy, assessment of the BAF due to a marginal increase in the demand for a specific feedstock in a region also requires selecting the size of the marginal unit. A challenge in determining of the size of the marginal unit is that it should be large enough to provide a statistically significant signal.  The market and resource impact of a small marginal change on BAF would likely be statistically insignificant.  Instead, modeling exercises could be undertaken to determine BAF thresholds (scales of consumption of an individual feedstock that shift the BAF) so that a “marginal” shift becomes a demand shift large enough to cross a BAF threshold.

The BAF of the marginal demand shock should be for the last ton of biomass above the reference case that includes the increased usage of the feedstock.  The BAF of the last ton of biomass from a specific feedstock in a region will provide the relevant signal of its carbon impact and provide the correct signals to influence feedstock choices towards those with relatively lower BAFs in a region. This reinforces the importance of calculating multiple BAFs for a single feedstock (e.g., corn stover) that reflect the diversity in production and use in a given region, for signals should be provided to move to feedstocks with lower BAFs, which may include both within a general feedstock type (corn stover produced more efficiently than another way of producing corn stover) and among general feedstock types (corn stover to roundwood) choice towards those with relatively lower BAFs in a region.

d. *Should shocks for different feedstocks be implemented in isolation (separate model runs), in aggregate (e.g., across the board increase in biomass usage endogenously allocated by the model across feedstocks), or something in between (e.g., separately model agriculture-derived and forest-derived feedstocks, but endogenously allocate within each category)?*
e. *For feedstocks that are produced as part of a joint production function, how should the shocks be implemented? (e.g., a general increase in all jointly produced products; or, a change in the relative prices of the jointly produced products leading to increased use of the feedstock, and decreased production of some other jointly produced products, but not necessarily an overall increase in production).*

We have lumped questions 2d and 2e together because they both relate to modeling feedstocks in isolation or jointly.

In the absence of a mandate for use of specific feedstocks or incentives for specific types of bioenergy production which could inform the structure of feedstock specific demand shocks that should be modelled, the most economically sensible approach is to model the aggregate demand for feedstocks because facilities are constantly seeking their least cost feedstock. An aggregate demand shock could be imposed on the model and used to determine demand for different feedstocks in different regions endogenously by the model. This would endogenously allocate demand across forestry and agricultural derived feedstocks as well as within each category.

A joint production function is relevant for feedstocks like corn stover (which is driven by corn production) and forest residue (which is driven by sawtimber harvests). For such feedstocks, if the model is used to endogenously determine the demand for those feedstocks as part of the overall mix of feedstocks to meet aggregate demand for biomass, then it will determine an economically viable quantity to be produced of those feedstocks while recognizing the practical limits on demand for the primary product. This would avoid possibly perverse results in which high levels of exogenously specified demand for residues drives the demand for the primary marketable product even though it is not economically viable to increase production of the primary product. However, this would allow the possibility that if one of these joint products has high market value then it could drive production of the primary product because returns from the biogenic feedstock more than compensate for the loss in returns from the primary product.

f. *How should scale of the policy be considered, particularly for default factors? (e.g., can a single set of default factors be applied to policies that lead to substantially different increases in feedstock usage)?*

Default BAFS ~~will definitely~~ vary by the scale of demand. It is unlikely that default BAFs can be robust across a wide range of scales of demand. The scale of demand is likely to influence the mix of feedstocks that is viable to produce because it can be expected to affect the market price of biomass.

Low levels of demand for biomass may be met relatively easily by crop residues, forest residues and mill residues; high levels of demand could lead to production of dedicated energy crops. The BAF of a feedstock in a region can be expected to vary depending on whether a policy requires 1 million ton increase in biomass or a 100 million ton increase in biomass.

In the absence of information about the scale of demand, BAFs could be determined for different threshold levels of aggregate demand for biomass and consequent feedstock/region-specific demand.

*g. Would the answers to any of the above questions differ when generating policy neutral default factors, versus generating factors directly tied to a specific policy?*

No – the same approach should be used in both cases. The only differences would be that BAFs that are tied to a particular policy would be based on simulating the aggregate and feedstock specific demand shock that is expected to emanate from that policy specifically while policy neutral factors would be based on various exogenously specified quantities of demand for biomass and corresponding endogenously determined levels of feedstock specific demand, and that different policies may require different production and use practices, and thus result in different BAFs. Isolating the extent to which expected increase in demand for biomass can be attributed to a specific policy (when there are multiple policies inducing a shift to renewable energy) is likely to be complicated.

*h. What considerations could be useful when evaluating the performance of the demand shock choice ex post, particularly if evaluating potential implications for/revisions of the future anticipated baseline and alternative scenarios going forward?*

A key consideration that could affect the performance of the demand shock ex-post is that the ex-ante allocation of feedstock-specific and region specific demand determined endogenously did not incorporate the role of BAFs in influencing demand. It is likely that the observed reality of feedstock demand after a policy using BAFs is implemented will differ from that determined ex-ante because the policy can be expected to increase demand for feedstocks with lower BAF and decrease demand for feedstocks with a high BAF. Since feedstock specific demand and the feedstock BAF are likely to be jointly determined in reality while the approach proposed above determines them sequentially some divergence between model simulated demand for feedstocks and observed reality is inevitable,

One option to reduce the extent of divergence between ex-ante and ex-post results on feedstock demand would be to run several iterations of the model after inserting the estimated BAFs in the model and re-simulating the allocation of aggregate biomass demand across different feedstocks and re-calculating the BAFs and so on till ex-ante and the modeled ex-post solutions converge.

An ex post evaluation would also allow revisions to EPA's estimates of feedstock demand changes (as discussed in response to Question 1d) based on updated data. To improve the performance of the model for assessing a BAF retrospectively, quantities of biomass feedstock (by feedstock category) used by stationary sources would be updated and predictions about biomass demand at stationary facilities could be tested against actual outcomes. Ex post, new data should improve the estimate of the portion of total biomass demand that is attributable to stationary facilities. This information could be used to improve BAF estimates prospectively for the future.

# A. APPENDIX A: CHARGE TO THE SAB

Part 1 – Future anticipated baseline approach and temporal scale

1. What criteria could be used when considering different temporal scales and the tradeoffs in choosing between them in the context of assessing the net atmospheric contribution of biogenic CO2 emissions from the production, processing, and use of biogenic material at stationary sources using a future anticipated baseline?

    a. Should the temporal scale for computing biogenic assessment factors vary by policy (e.g., near-term policies with a 10-15 year policy horizon vs mid-term policies or goals with a 30-50 year policy horizon vs long-term climate goals with a 100+ year time horizon), feedstocks (e.g., long rotation vs annual/short-rotation feedstocks), landscape conditions, and/or other metrics? It is important to acknowledge that if temporal scales vary by policy, feedstock or landscape conditions, or other factors, it may restrict the ability to compare estimates/results across different policies or different feedstock types, or to evaluate the effects across all feedstock groups simultaneously.
        i. If temporal scales for computing biogenic assessment factors vary by policy, how should emissions that are covered by multiple policies be treated (e.g., emissions may be covered both by a short-term policy, and a long-term national emissions goal)? What goals/criteria might support choices between shorter and longer temporal scales?
        ii. Similarly, if temporal scales vary by feedstock or landscape conditions, what goals/criteria might support choices between shorter and longer temporal scales for these metrics?
        iii. Would the criteria for considering different temporal scales and the related tradeoffs differ when generating policy neutral default biogenic assessment factors versus crafting policy specific biogenic assessment factors?
    b. Should the consideration of the effects of a policy with a certain end date (policy horizon) only include emissions that occur within that specific temporal scale or should it consider emissions that occur due to changes that were made during the policy horizon but continue on past that end date (emissions horizon)?
    c. Should calculation of the biogenic assessment factor include all future fluxes into one number applied at time of combustion (cumulative – or apply an emission factor only once), or should there be a default biogenic assessment schedule of emissions to be accounted for in the period in which they occur (marginal – apply emission factor each year reflecting current and past biomass usage)?
    d. What considerations could be useful when evaluating the performance of a future anticipated baseline application on a retrospective basis (e.g., looking at the future anticipated baseline emissions estimates versus actual emissions *ex post*), particularly if evaluating potential implications for/revisions of the future anticipated baseline and alternative scenarios going forward?

**Part 2 – Scales of biomass use when applying future anticipated baseline approach**

EPA seeks guidance on technical considerations concerning how to select model perturbations ('shocks') for future anticipated baseline simulations estimating the net atmospheric contribution of biogenic CO2 emissions from the production, processing, and use of biogenic material at stationary sources, using the above referenced components of the revised framework report as the starting point for the SAB Panel's discussion. As the SAB Panel recommended developing default assessment factors by feedstock category and region that may need to be developed outside of a specific policy context, and as the framework could be also be used in specific policy contexts, the questions below relate to the choice of model shocks both within and outside of a specific policy context.

2. What is/are the appropriate scale(s) of biogenic feedstock demand changes for evaluation of the extent to which the production, processing, and use of biogenic material at stationary sources results in a net atmospheric contribution of biogenic CO2 emissions using a future anticipated baseline approach? In the absence of a specific policy to model/emulate, are there general recommendations for what a representative scale of demand shock could be?
    a. Should the shock reflect a small incremental increase in use of the feedstock to reflect the marginal impact, or a large increase to reflect the average effect of all users?
    b. What should the general increment of the shock be? Should it be specified in tons, or as a percentage increase?
    c. Should the shock be from a business as usual baseline, or from a baseline that includes increased usage of the feedstock (i.e., for a marginal shock, should it be the marginal impact of the first ton, or the marginal impact of something approximating the last ton)?
    d. Should shocks for different feedstocks be implemented in isolation (separate model runs), in aggregate (e.g., across the board increase in biomass usage endogenously allocated by the model across feedstocks), or something in between (e.g., separately model agriculture-derived and forest-derived feedstocks, but endogenously allocate within each category)?
    e. For feedstocks that are produced as part of a joint production function, how should the shocks be implemented? (e.g., a general increase in all jointly produced products; or, a change in the relative prices of the jointly produced products leading to increased use of the feedstock, and decreased production of some other jointly produced products, but not necessarily an overall increase in production).
    f. How should scale of the policy be considered, particularly for default factors? (e.g., can a single set of default factors be applied to policies that lead to substantially different increases in feedstock usage)?
    g. Would the answers to any of the above questions differ when generating policy neutral default factors, versus generating factors directly tied to a specific policy?
    h. What considerations could be useful when evaluating the performance of the demand shock choice *ex post*, particularly if evaluating potential implications for/revisions of the future anticipated baseline and alternative scenarios going forward?

# B. APPENDIX B: ALTERNATE FRAMEWORK BASED ON CARBON STOCKS

## Introduction

The following appendix describes the alternative biogenic carbon accounting framework being proposed by the SAB. Example cases of how the framework might be used are provided in Appendix D. 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?" (U.S. EPA 2014).

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 the EPA could be examined at multiple landscape 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 earlier SAB recommendation (U.S. EPA SAB 2012) it is assumed that it would be applied to the landscape to regional level. Further, it is assumed 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 stores 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). The scenario in which biogenic feedstock use is increased is 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 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 D 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 the system boundaries in the proposed alternative framework are not the geographical boundaries of the system. They are 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 (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 they mix the aspect of time being considered (i.e., a time point versus a time period) and the way the data are being treated (i.e., differenced, summed, or averaged). The subscripts described below are used in the alternative framework to indicate the timeframe being used and how the primary information (which for NBE or net biogenic emissions is the difference in stores between the reference and policy scenarios) is being treated:

1. 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.

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

3. 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.

4. 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.

5. 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.

6. 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.

7. 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:

$$BAF_x = NBE_x / PGE_x \qquad \text{(Eq. B-1)}$$

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:

$$BAF_{Bt}=NBE_{Bt}/PGE_{Bt} \qquad \text{(Eq. B-2)}$$

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:

$$PGE_{Bt} = \sum_{t=0}^{t} PGE_{\Delta t} \qquad \text{(Eq. B-3)}$$

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:

$$NBE_{Bt}=TC_{reference\ t} - TC_{policy\ t} \qquad \text{(Eq. B-4)}$$

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:

$$NBE_{Bt}= (CL_{reference\ t} - CL_{policy\ t}) + (CD_{reference\ t} - CD_{policy\ t}) + (CS_{reference\ t} - CS_{policy\ t}) + (CP_{reference\ t} - CP_{policy\ t}) + (CW_{reference\ t} - CW_{policy\ t}) + (TL_{reference\ t} - TL_{policy\ t}) \qquad \text{(Eq. B-5)}$$

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 ∆t (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:

$$NBE_{B\Delta t} = \Delta(TC_{reference\ t} - TC_{policy\ t}) \qquad \text{(Eq. B-6)}$$

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

$$\Delta(TC_{reference\ t} - TC_{policy\ t}) = (TC_{reference\ t} - TC_{policy\ t}) - (TC_{reference\ t-1} - TC_{policy\ t-1}) \qquad \text{(Eq. B-7)}$$

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:

$$NBE_{Bt} = \sum_{t=0}^{t} \Delta(TC_{reference\ t} - TC_{policy\ t}) = \sum_{t=0}^{t} NBE_{B\Delta t} \qquad \text{(Eq. B-8)}$$

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:

$$NBE_{B\Delta t} = \sum_{t=0}^{t} \Delta(CLrt - CLpt) + \sum_{t=0}^{t} \Delta(CDrt - CDpt) + \sum_{t=0}^{t} \Delta(CSrt - CSpt) + \sum_{t=0}^{t} \Delta(CPrt - CPpt) + \sum_{t=0}^{t} \Delta(CWrt - CWpt) + \sum_{t=0}^{t} \Delta(TLrt - TLpt) \qquad \text{(Eq. B-9)}$$

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:

$$NBE_{Bt} = \sum_{t=0}^{t} \Delta((CLrt + CDrt + CSrt + CPrt + CWrt + TLrt) - (CLpt + CDpt + CSpt + CPpt + CWpt + TLpt)) \qquad \text{(Eq. B-10)}$$

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:

$$BAF_{B\Delta t}=NBE_{B\Delta t}/PGE_{B\Delta t} \quad \text{(Eq. B-11)}$$

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 C 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:

$$BAF_{\Delta t} = NBE_{\Delta t} / PGE_{\Delta t} \quad \text{(Eq. B-12)}$$

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

$$NBE_{\Delta t} = BAF_{\Delta t} \quad \text{(Eq. B-13)}$$

The final equation approximating $BAF_t$ is therefore:

$$BAF_t \approx \sum_{t=0}^{t} BAF_{\Delta t} / t \quad \text{(Eq. B-14)}$$

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:

$$BAF_{B\Sigma t}=NBE_{B\Sigma t}/PGE_{B\Sigma t} \quad \text{(Eq. B-15)}$$

where

$$NBE_{B\Sigma t}=\sum_{t=0}^{t} NBE_{Bt} \quad \text{(Eq. B-16)}$$

and

$$PGE_{B\Sigma t}=\sum_{t=0}^{t} PGE_{Bt} \quad \text{(Eq. B-17)}$$

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 C 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:

$$BAF_t = NBE_t / PGE_t \quad \text{(Eq. B-18)}$$

which can be rearranged as:

$$NBE_t = BAF_t * PGE_t \quad \text{(Eq. B-19)}$$

or since $PGE_t$ can be represented by time t:

$$NBE_t = BAF_t * t \quad \text{(Eq. B-20)}$$

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

$$BAF_{\Sigma t} \approx \sum_{t=0}^{t} BAF_t * t / \sum_{t=0}^{t} \quad \text{(Eq. B-21)}$$

**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 $CO_2$ emissions, i.e. the length of time emissions are resident in the atmosphere. To take account of residence time, the proposed $BAF_{B\Sigma t}$ would accumulate the annual differences in carbon stocks on the land over the entire time horizon. By contrast, the 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, the 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, this total cumulative BAF is 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 the 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 C for a graphical **Error! Reference source not found.**.

**Analytical solutions to Net Biogenic Emission (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):

$$O = k\ TC_T \qquad \text{(Eq. B-22)}$$

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

$$TC_T = I/k \qquad \text{(Eq. B-23)}$$

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:

$$TC_{reference\ T} = I/k > TC_{policy\ T} = I/(k(1+n)) \qquad \text{(EQ. B-24)}$$

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:

$$TC_{reference\ T} = I/k = TC_{policy\ T} = I(1+n)/(k(1+n)) \qquad \text{(Eq. B-25)}$$

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.

$$TC_{reference\ T} = I/k = TC_{policy\ T} = I/k \qquad \text{(Eq. B-26)}$$

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

$$TC_{reference\ T} = I/k < TC_{policy\ T} = I(1+n)/k \qquad \text{(Eq. B-27)}$$

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 C.

**System Boundaries**

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

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

2. 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.

3. 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.

4. 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 products to which the carbon is sent. By not discriminating among products, the use of 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. 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.

# C. APPENDIX C: A GRAPHICAL COMPARISON BETWEEN $BAF_T$ AND $BAF_{B\Sigma T}$

This appendix provides a series of graphs to allow a visual comparison of the SAB's proposed $BAF_{B\Sigma t}$ to the EPA's $BAF_T$. As shown in Figure C-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, the 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*. The SAB's proposed $NBE_{\Sigma t}$ is again shown in Figure C-2 as the shaded area under the orange line which represents the cumulative difference in stores. Figure C-4 plots 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 C-5 which dramatically shows the difference between carbon stores *over a period of time (ΣT)* versus *at a point in time (T)*.

Since the SAB is proposing a ΣT measure that is "cumulative" and EPA also has a measure they are calling "cumulative," it is necessary to to distinguish between these measures 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, the SAB proposes 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, an explanation of how the terms are used and what they represent is provided.

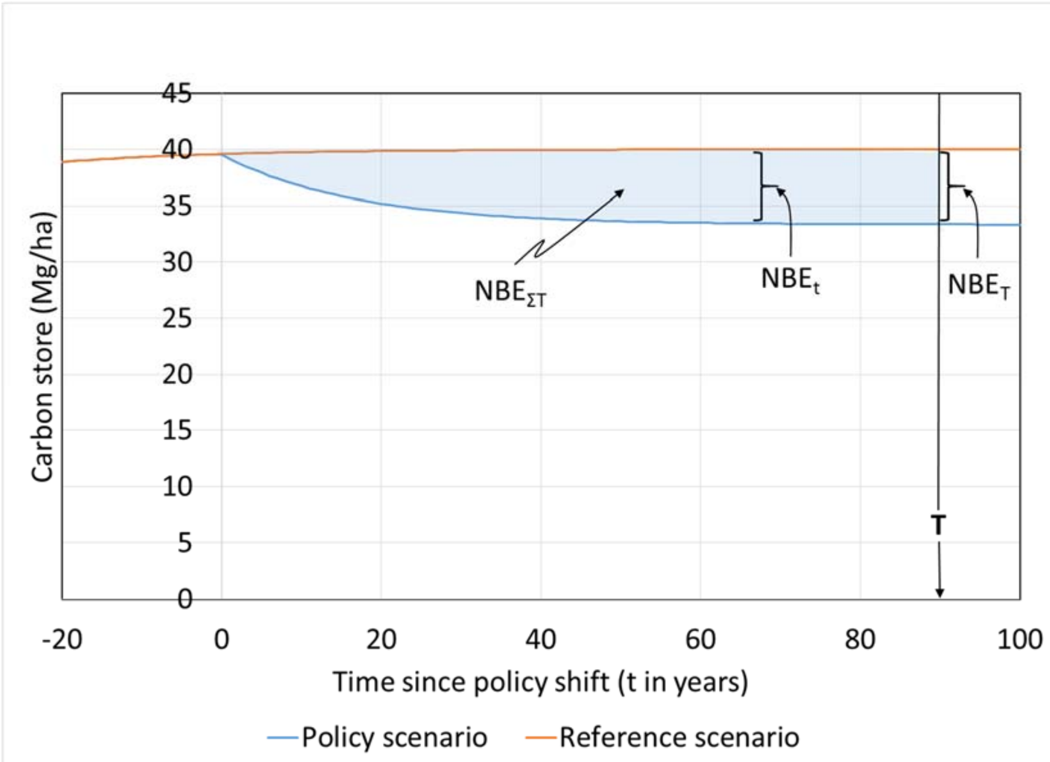


**Figure C-1. A graphical illustration of the terms used in the proposed new framework as illustrated using Case 1: Decreasing carbon described in Appendix D.**

In Figure C-1 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., capital T). The difference between these two scenarios at time T is indicated by NBE$_T$. For a fuller examination of Case 1 see Appendix D.

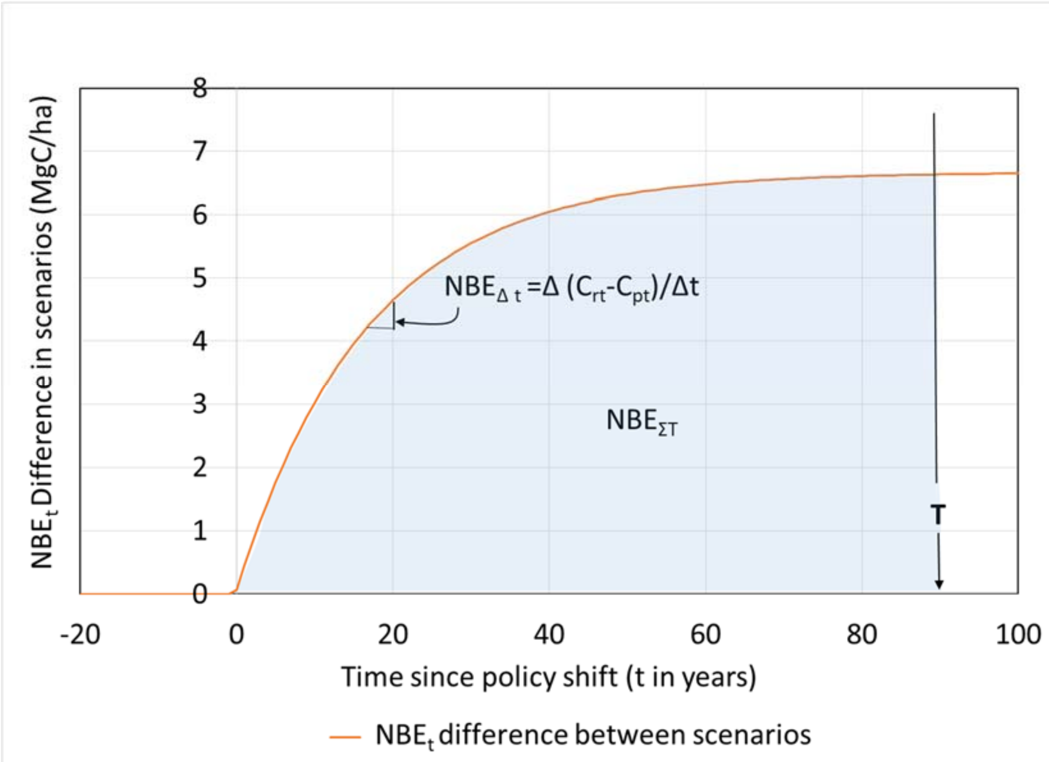


**Figure C-2. The carbon stores differences (NBE$_t$) between the policy and reference scenarios as a function of time t.**

In Figure C-2 the carbon store difference between the policy and reference scenarios 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 D). 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".

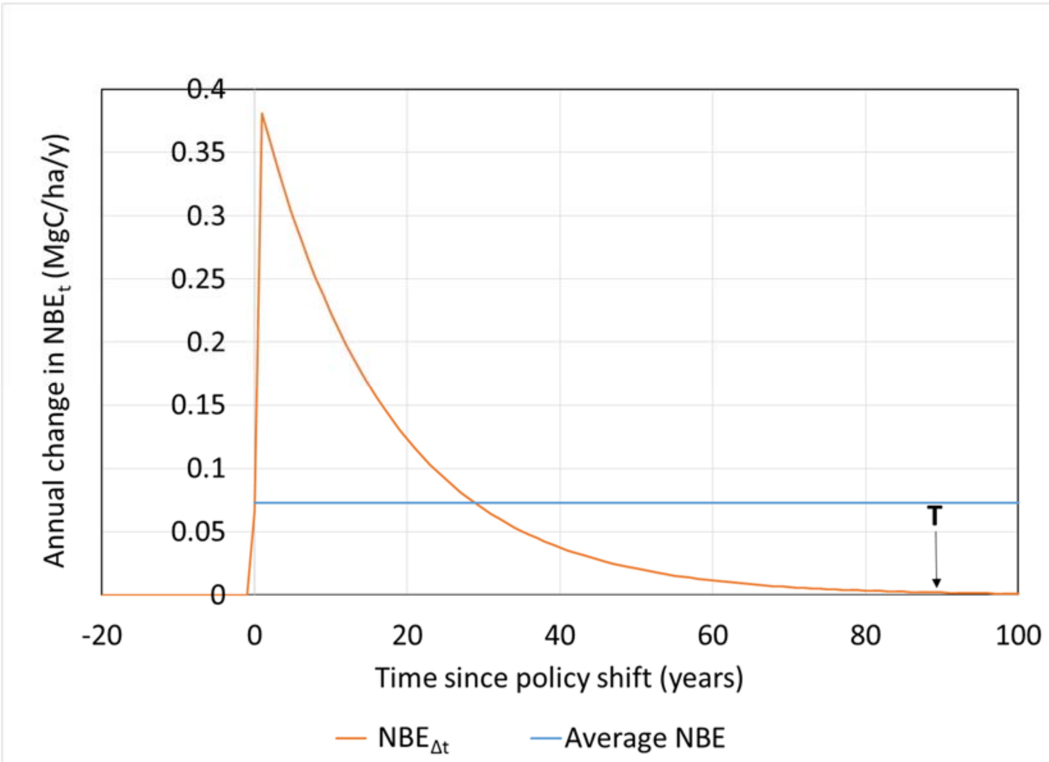


**Figure C-3. The annual change in NBE$_t$. (called NBE$_{\Delta t}$ and depicted by the orange line)**.

Figure C-3 shows that 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.

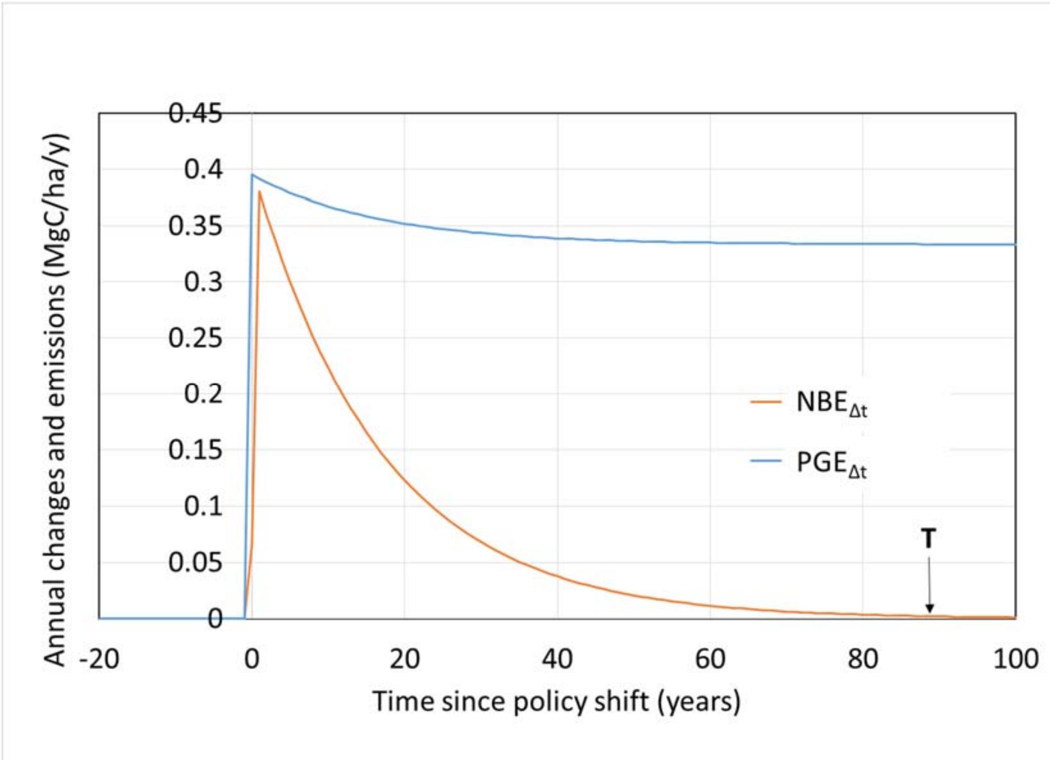


**Figure C-4. BAF's calculated by dividing the Net Biogenic Emissions (NBE) by the Potential Gross Emissions (PGE) associated with burning biogenic carbon for energy.**

In Figure C-4 the annual changes in $NBE_{\Delta t}$ and $PGE_{\Delta t}$ are represented by the the orange and blue lines, 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 C-5.

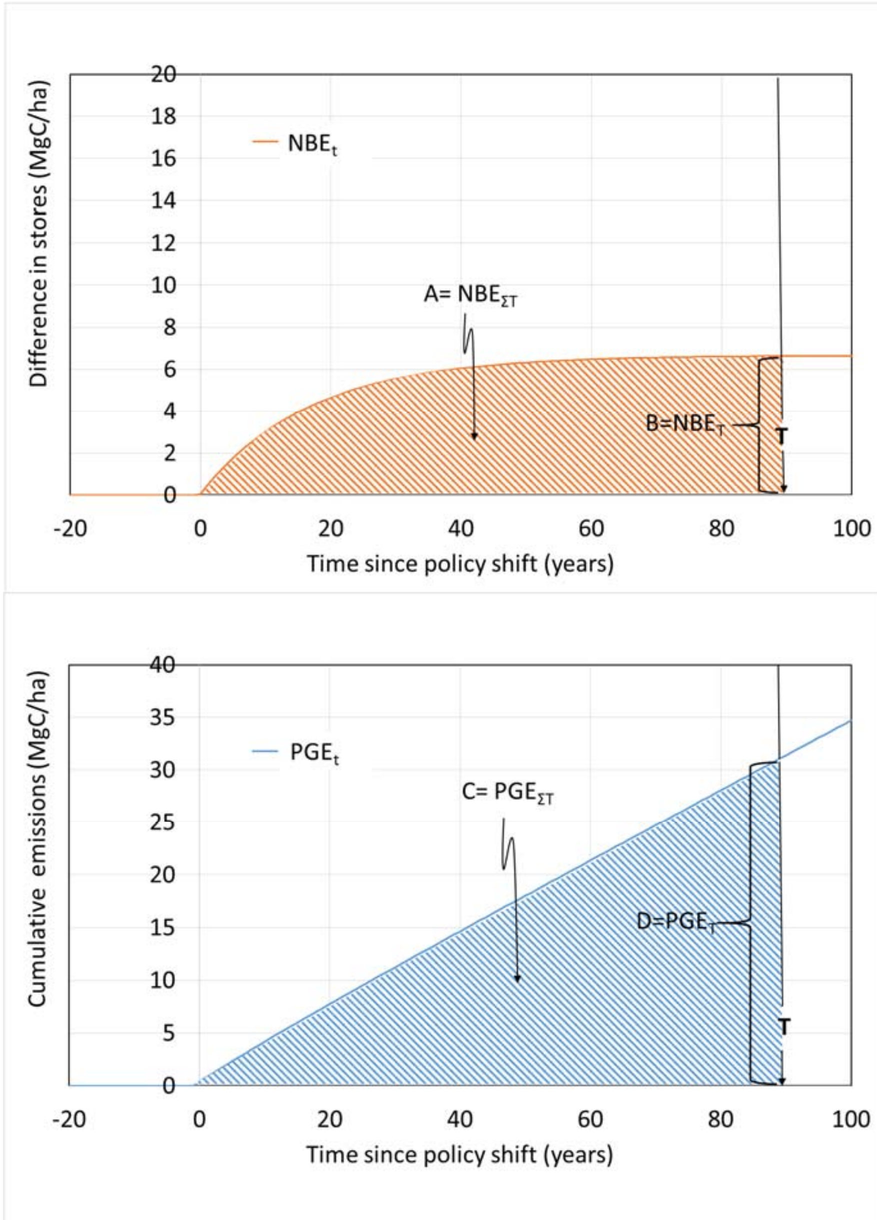


**Figure C-5. The cumulative effects of a policy represented at a point in time (T) or over a period of time (ΣT).**

As depicted in Figure C-5, the cumulative effects of a policy can be represented 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.

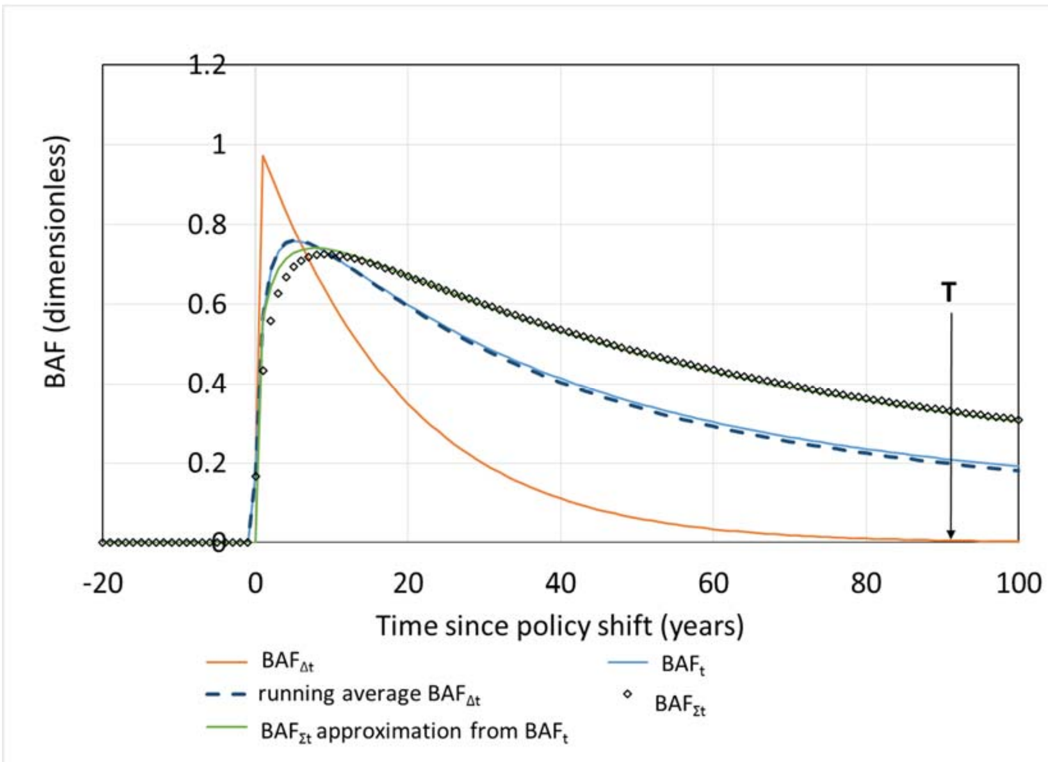


**Figure C-6. The results of the various ways that BAF's can be calculated.**

Figure C-6 shows the results of the various ways that BAFs can be calculated. 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 B. This approximation is quite similar to $BAF_{\Sigma T}$ (0.329).

# D. APPENDIX D: 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 B 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 B; 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 $\Delta t$ 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 $\Sigma T$ is used. If the sum over an interval over t years is used, the subscript $\Sigma t$ 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, the 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.

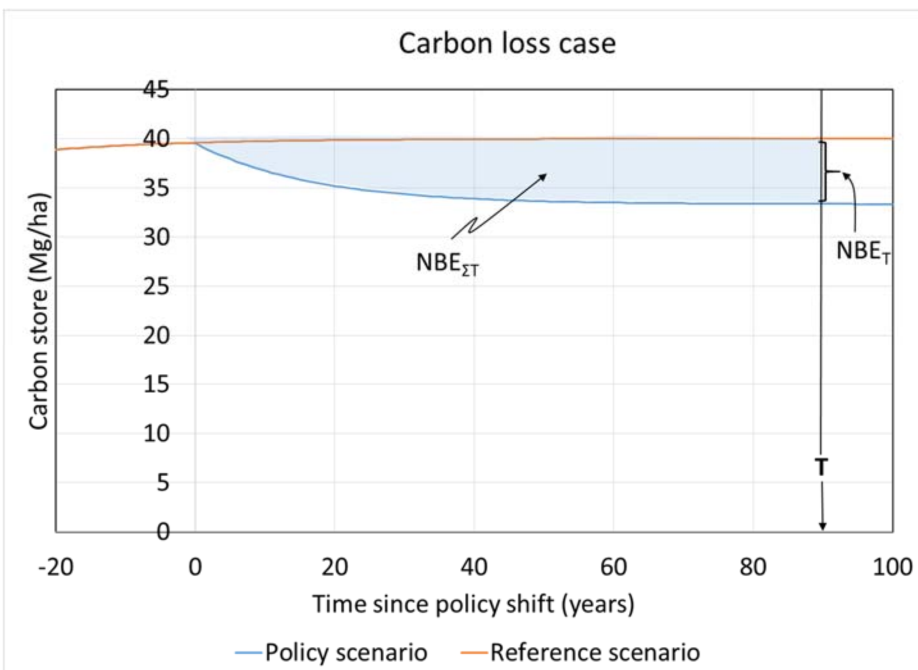


**Figure D-1. Carbon Loss Case**

Figure D-1. shows that 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 B, 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.

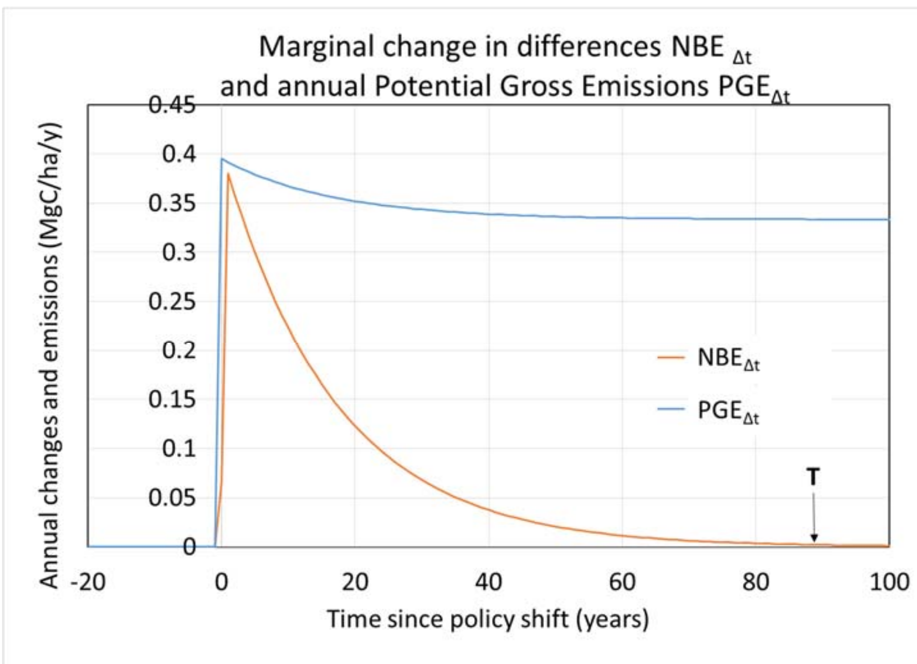


**Figure D-2. Rate at which differences between reference and policy scenarios is growing ($NBE_{\Delta t}$) and annual potential gross emissions $PGE_{\Delta t}$)**

Figure D-2 shows 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 D-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.

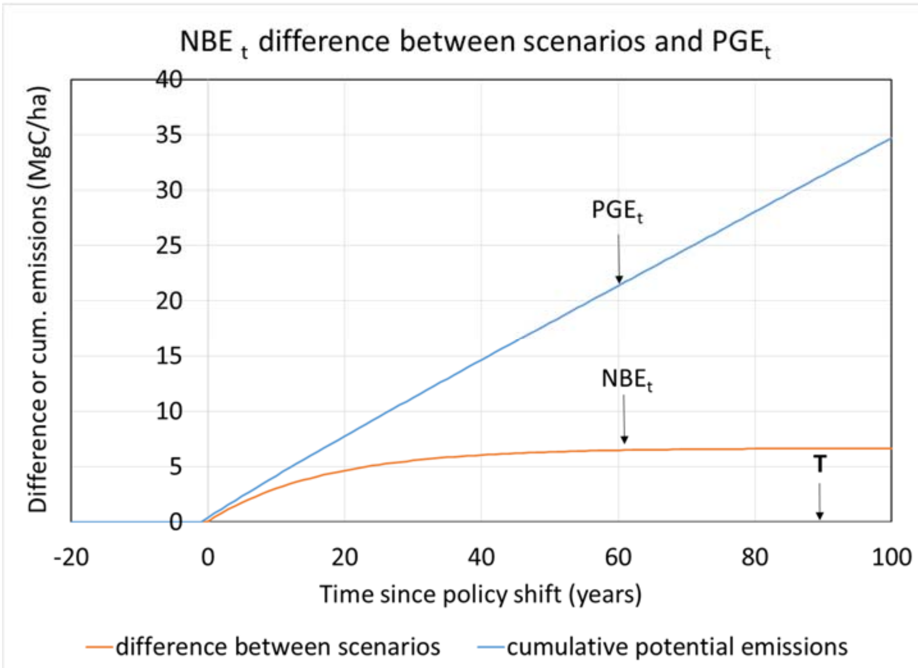


**Figure D-3. Time course of the difference between scenarios ($NBE_t$) and cumulative potential gross emissions ($PGE_t$)**

The BAF term can be calculated using different temporal concepts, the result of these calculations is shown in Figure D-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.

The SAB is 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.

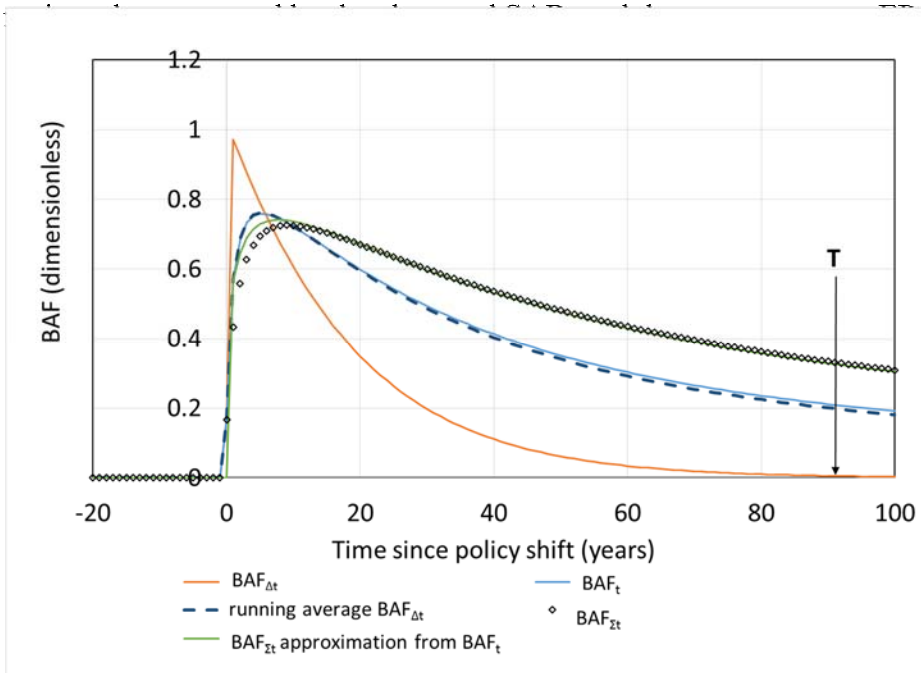


**Figure D-4. Comparison of BAF calculation methods for the case in which biofuel harvest reduces carbon stores relative to the reference scenario.**

**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 D-5).

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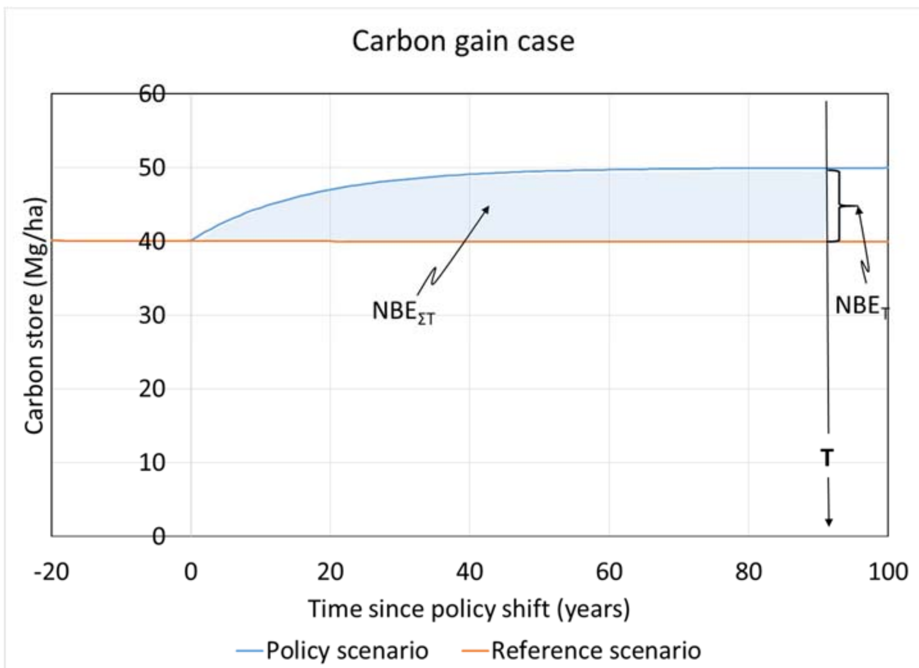


**Figure D-5. Carbon gain case**

Figure D-5 shows 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 D-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.

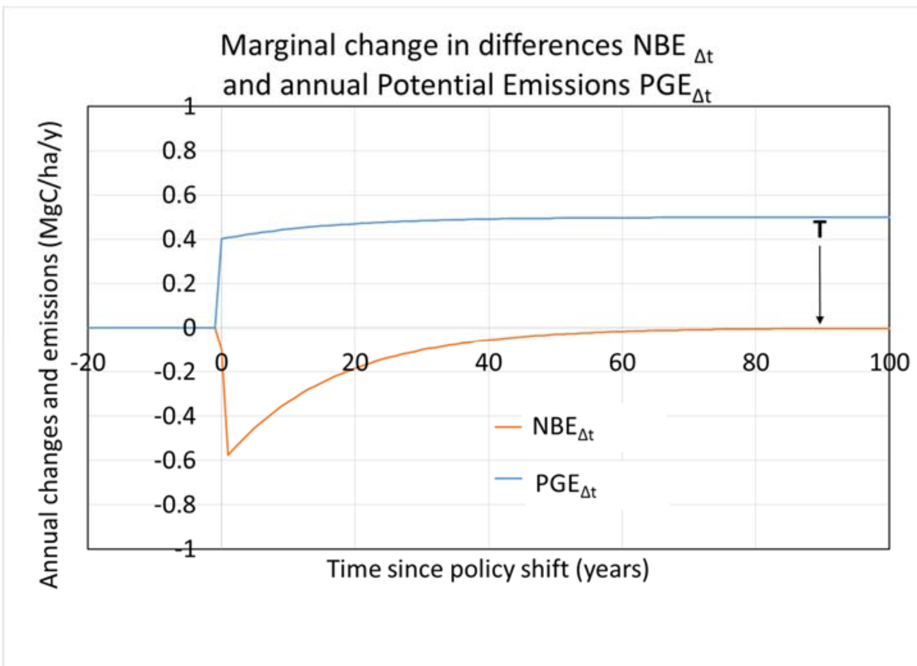


**Figure D-6. The rate at which the difference between the reference and policy scenarios is growing ($NBE_{\Delta t}$) and the potential gross emissions from biofuel use each year when there is a gain of carbon caused by the policy scenario.**

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 D-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 D-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.

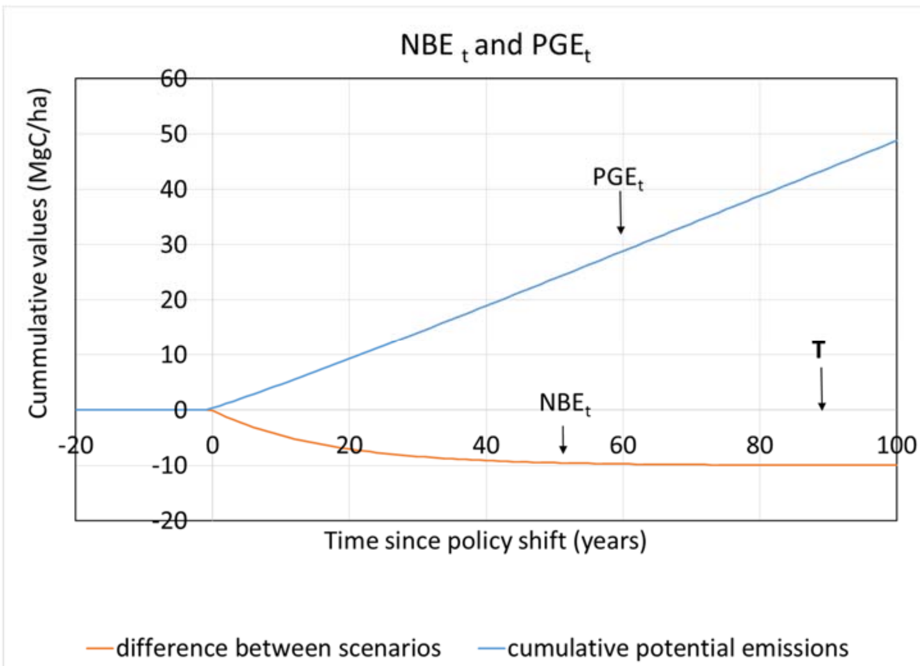


**Figure D-7. The time course of the difference between scenarios ($NBE_t$) and cumulative potential gross emissions ($PGE_t$) when there is a gain of carbon caused by the policy scenario**

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 D-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.

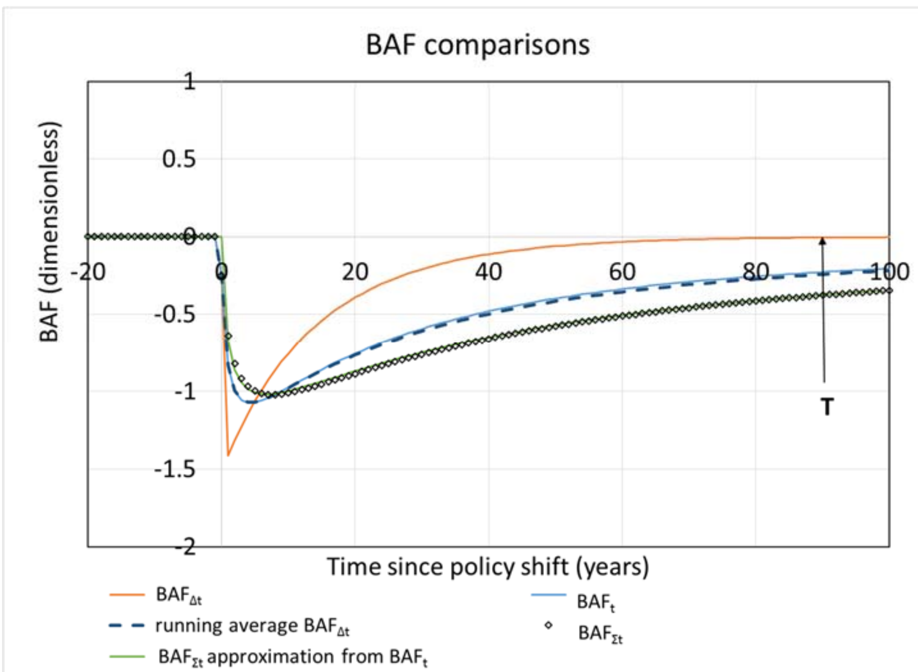


**Figure D-8. Comparison of BAF calculation methods for the case in which biofuel harvest increases carbon stores relative to the reference scenario.**

### 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 D-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.

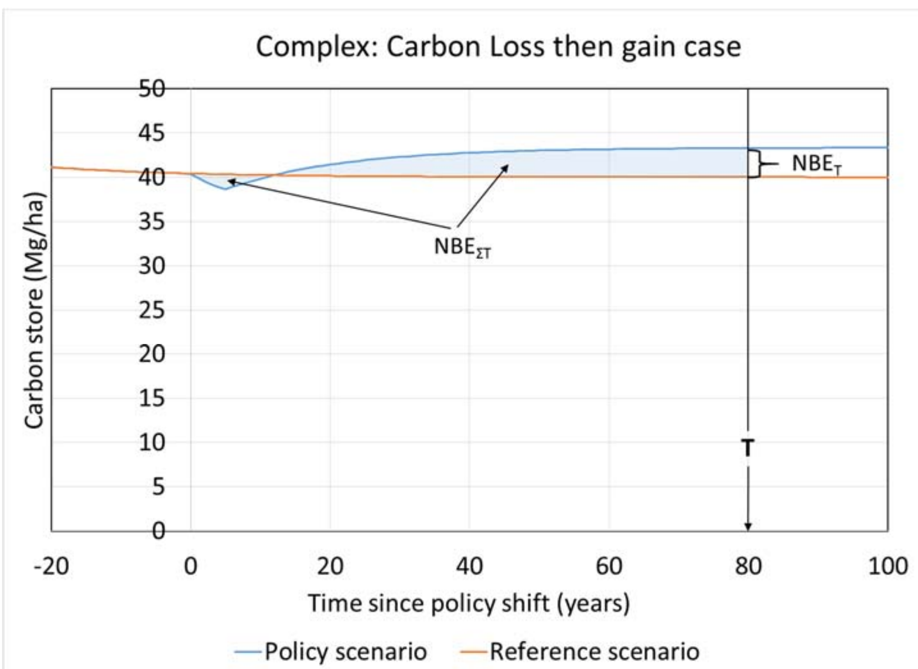


**Figure D-9. Carbon loss then gain case**

Figure D-9 showsthe 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 D-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.

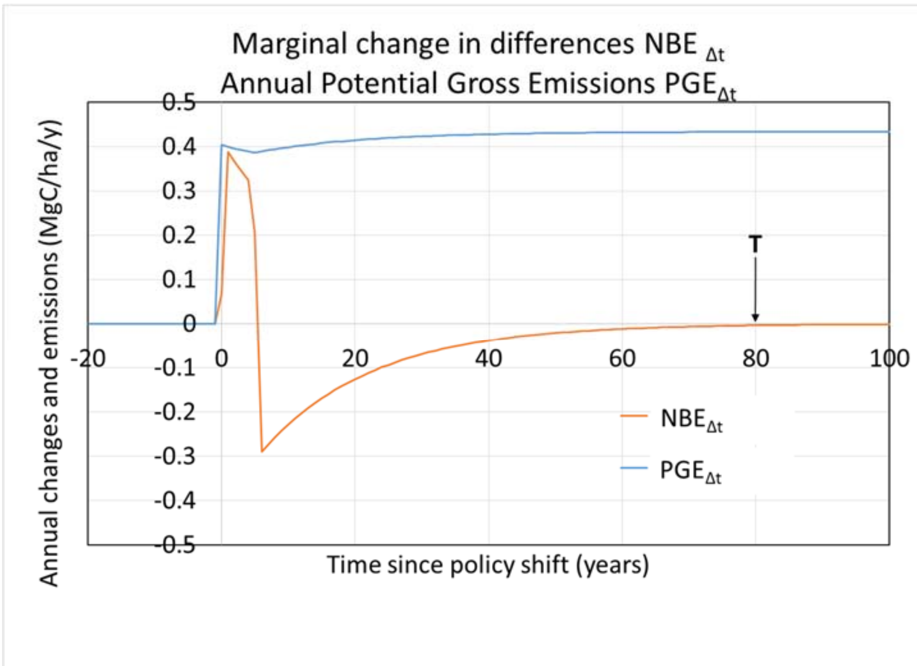


**Figure D-10. The rate at which the difference between the reference and policy scenarios is growing ($NBE_{\Delta t}$) and the potential gross emissions from biofuel use each year when there is a loss then a gain of carbon caused by the policy scenario.**

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 D-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.

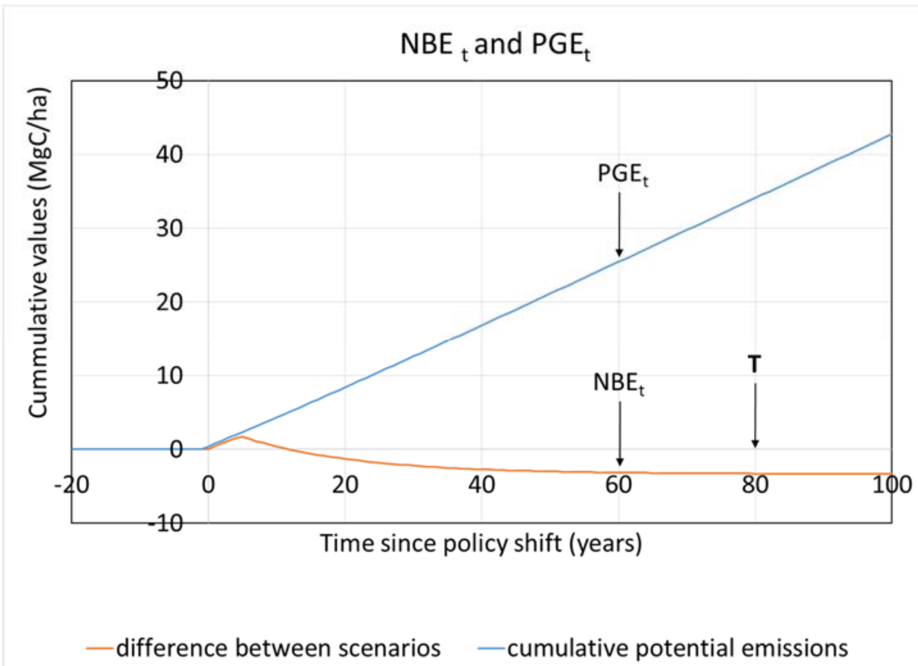


**Figure D-11. The time course of the difference between scenarios ($NBE_t$) and cumulative potential gross emissions ($PGE_t$) when there is a loss then gain of carbon caused by the policy scenario.**

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 D-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.

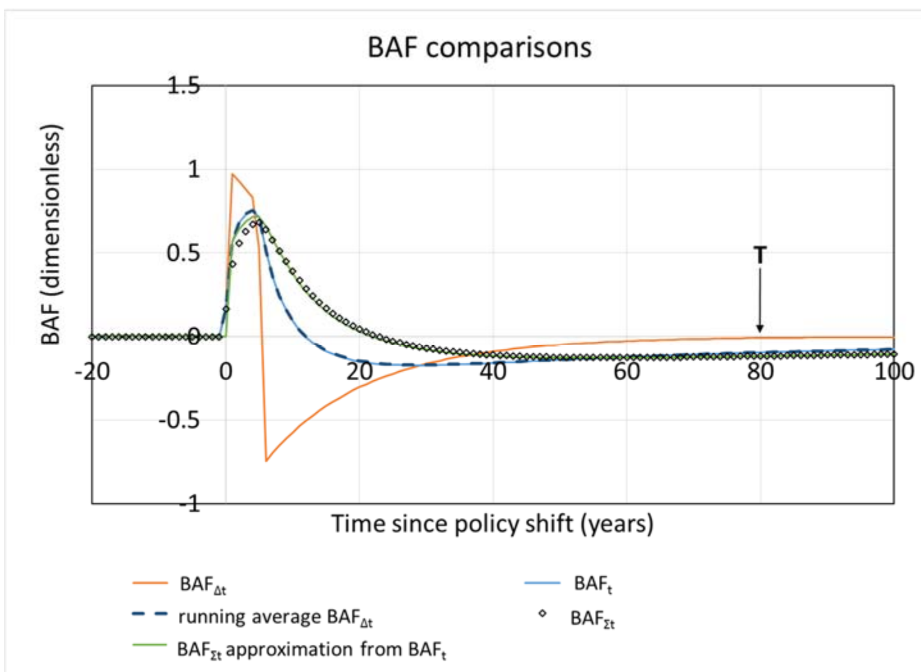


**Figure D-12. Comparison of BAF calculation methods for the case in which biofuel harvest decreases and then increases carbon stores relative to the reference scenario.**

**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 D-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.

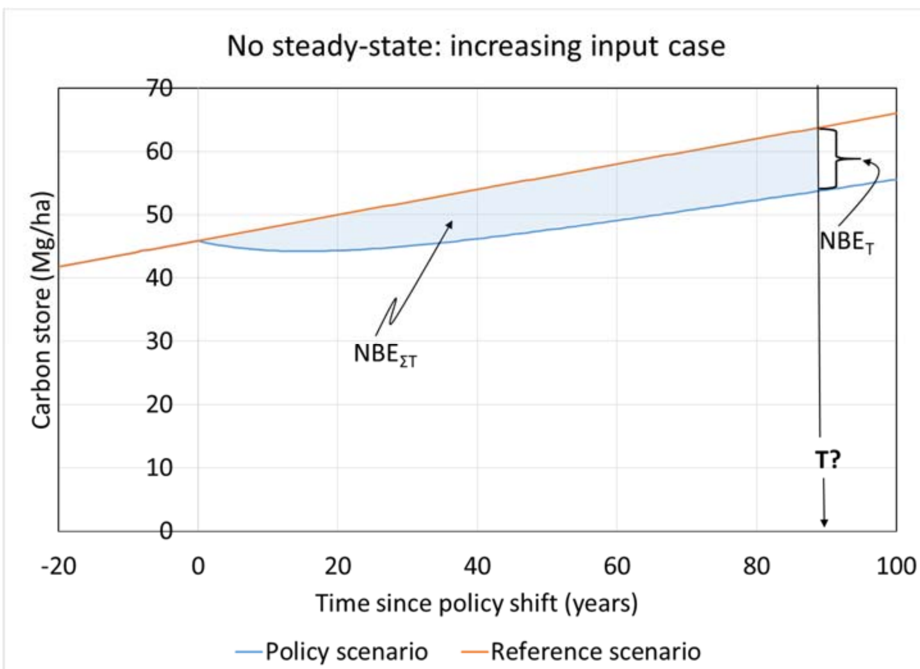


**Figure D-13. The landscape level average carbon stores for the case in which harvest for biofuels (the policy scenario) leads to a decrease in carbon stores compared to the reference scenario, but both scenarios have increasing carbon stores relative to time 0**

Figure D-13 shows 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 D-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.

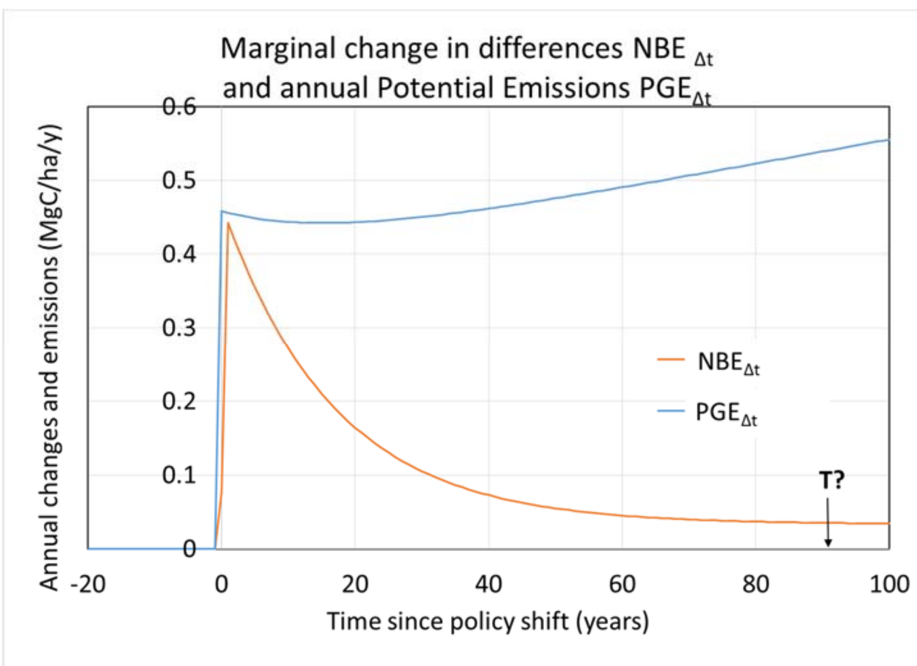


**Figure D-14. The rate at which the difference between the reference and policy scenarios is growing ($NBE_{\Delta t}$) and the potential gross emissions from biofuel use**

**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 D-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.

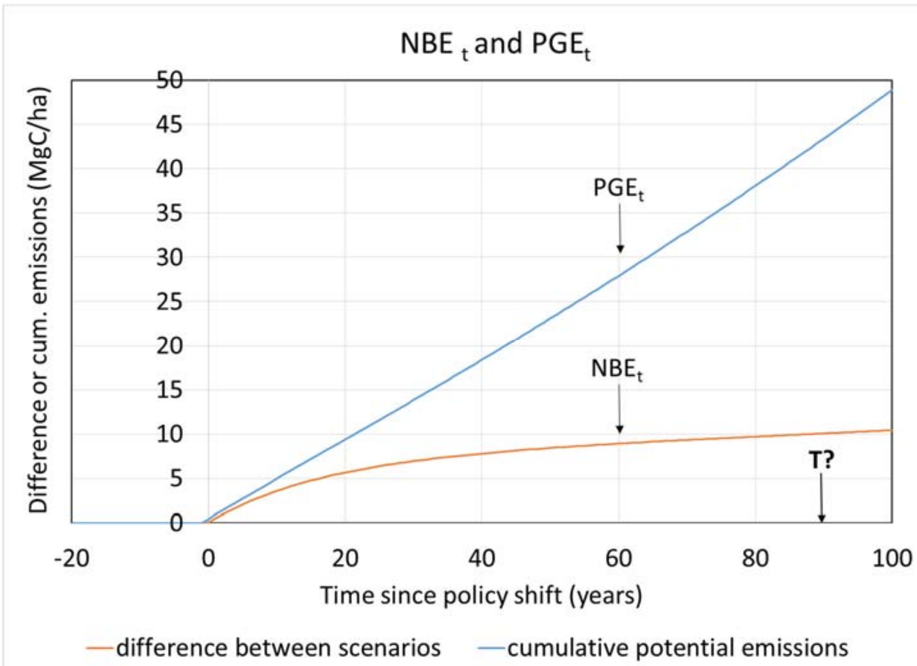


**Figure D-15. The time course of the difference between scenarios ($NBE_t$) and cumulative potential gross emissions ($PGE_t$) when both the reference and the policy scenario have an increase in input related to an environmental change.**

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 D-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.

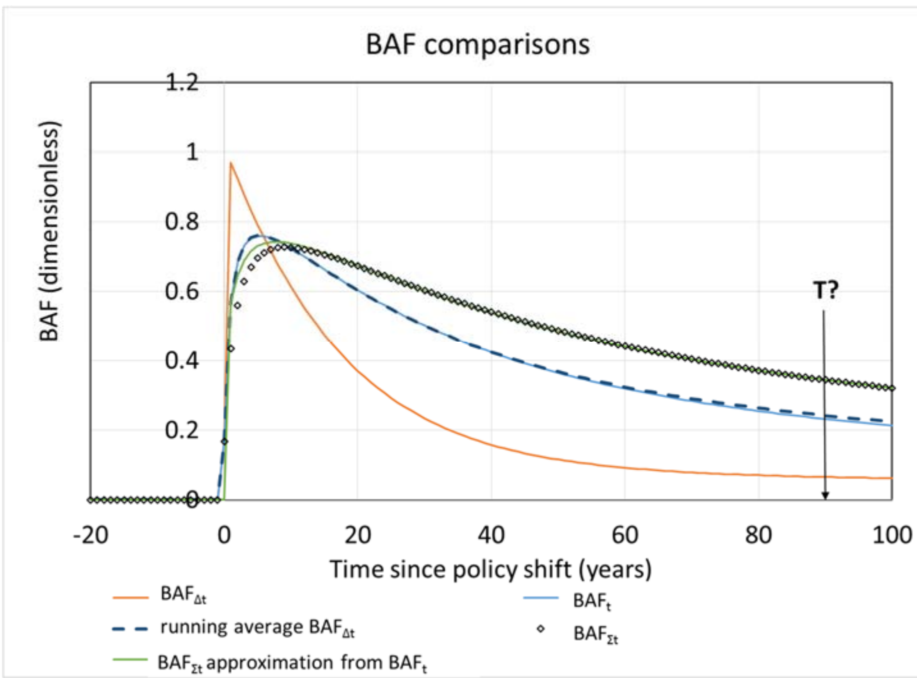


**Figure D-16. Comparison of BAF calculation methods for the case when both the reference and the policy scenario have an increase in input related to an environmental change.**

### 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 D-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.

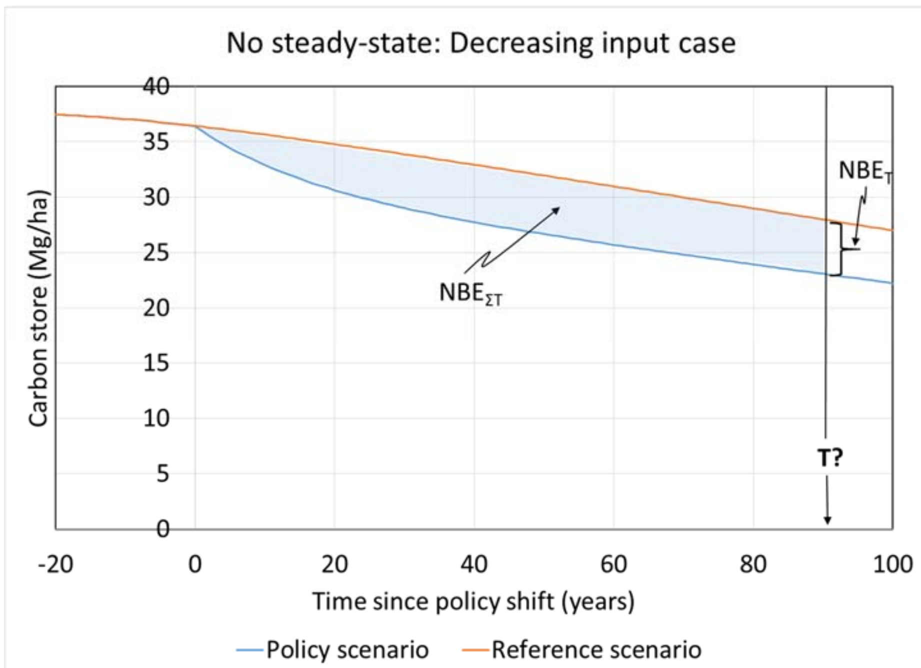


**Figure D-17. The landscape level average carbon stores for the case when increased harvest for biofuels (the policy scenario) leads to a decrease in carbon stores compared to the reference scenario, but both scenarios have decreasing carbon stores relative to time 0 caused by an environmentally driven decline in inputs**

Figure D-17 shows 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 D-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.

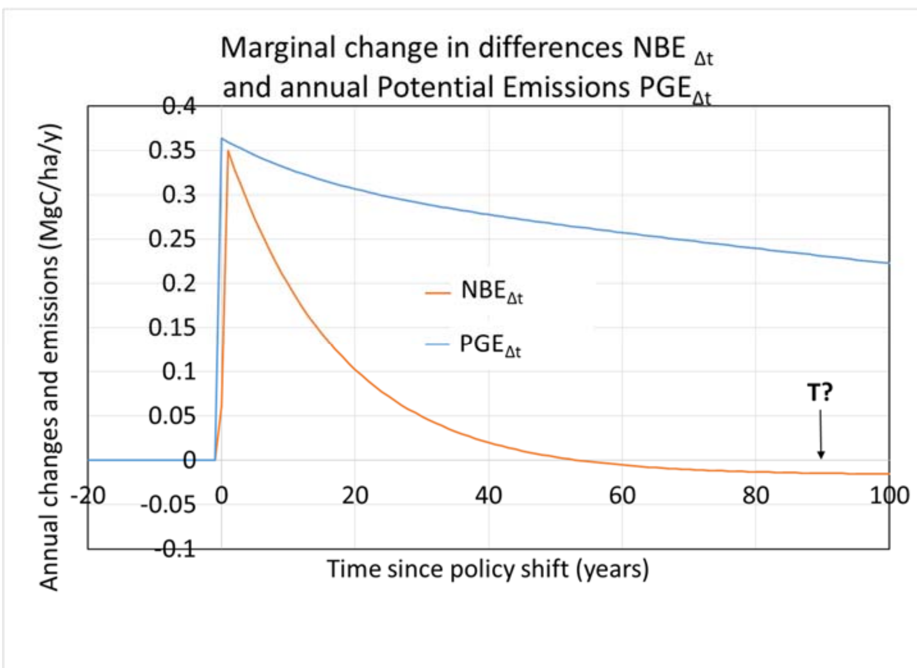


**Figure D-18. The rate at which the difference between the reference and policy scenarios is growing ($NBE_{\Delta t}$) and the potential gross emissions from biofuel use each year when both the reference and the policy scenario have a decrease in input related to an environmental change.**

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 D-19).

Figure D-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.

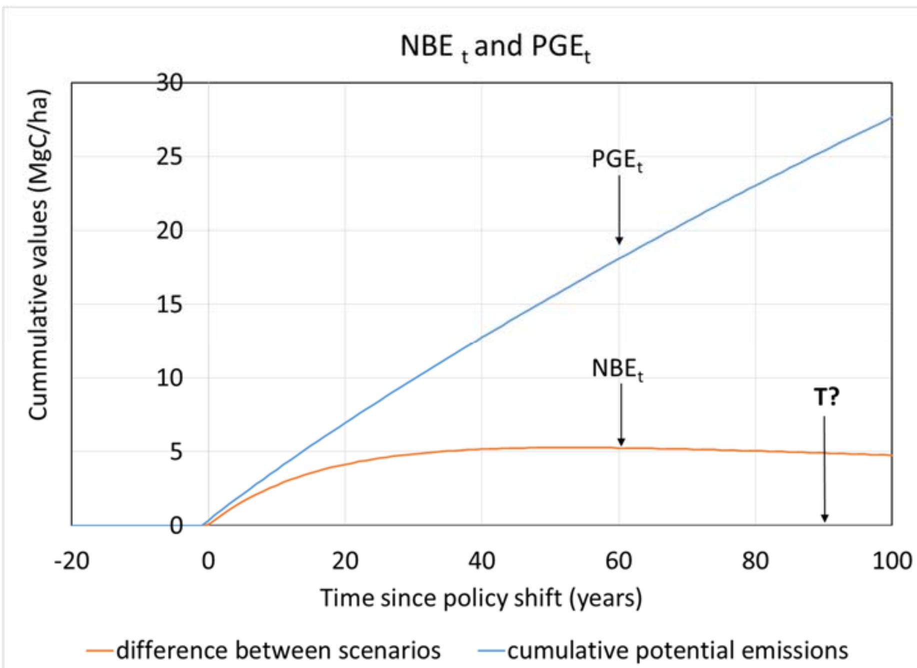


**Figure D-19. The time course of the difference between scenarios ($NBE_t$) and cumulative potential gross emissions ($PGE_t$) when both the reference and the policy scenario have a decrease in landscape input related to an environmental change**

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 D-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.

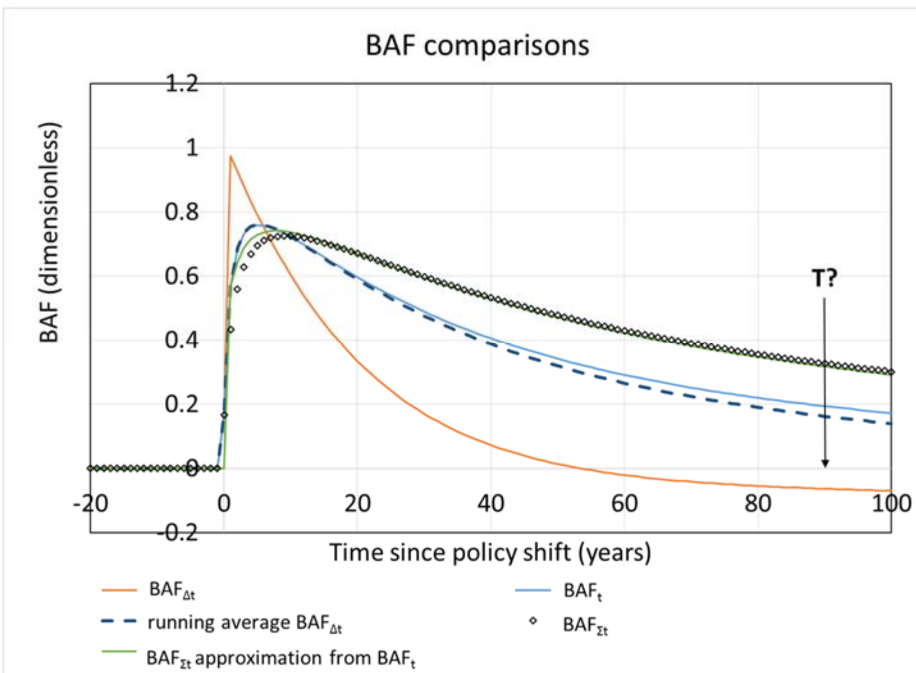


**Figure D-20. Comparison of BAF calculation methods for the case when both the reference and the policy scenario have a decrease in input related to an environmental change.**

## 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 | 0.329 | -0.378 | -0.120 | 0.344 | 0.317 |

| | | | | | |
|---|---|---|---|---|---|
| using $BAF_t$ | | | | | |
| $BAF_{\Sigma T}$ Cumulative Stock Difference-Based rate | 0.334 | -0.337 | -0.112 | 0.344 | 0.326 |
| T years | 90 | 90 | 80 | ≈90 | ≈90 |

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