DATE

EPA-SAB-16-xxx

The Honorable Gina McCarthy
Administrator
U.S. Environmental Protection Agency
1200 Pennsylvania Avenue, NW
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 is to develop a method for calculating the adjustment, or Biogenic Assessment Factor (BAF), for carbon emissions associated with the combustion of biogenic feedstocks taking into account the biological carbon cycle effects associated with their 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. 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 emissions that might have occurred with an alternate fate had it not been used for fuel.

The 2014 Framework is a revision of the 2011 Framework which the SAB previously reviewed. We are pleased that the 2014 Framework incorporated some of the SAB's prior advice and advanced the analytical foundation for making determinations about the 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 discussion of the trade-offs inherent in the selection of a temporal scale for considering net emissions;

- It has developed representative BAFs by feedstock and region in view of the data demands of a facility-specific BAF calculation;
- It includes a 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
- It offers an approach to construct an anticipated baseline that allows assessment of the *additional* CO_2 emissions that might be attributed to biogenic feedstocks as a result of changes in biomass feedstock demand.

The 2014 Framework does not, however, provide the policy context, specific BAF calculations for that context or the implementation details the SAB previously requested. In fact, the lack of information in both Frameworks on how the EPA may use them made it 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, provided explicit BAF calculations and defined its legal boundaries regarding upstream and downstream emissions in the feedstock life cycles. The 2014 Framework lacks concreteness and is written in a way that is too flexible, with too many possibilities. Rather than offering a lengthy menu of calculation options, the 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.*

That said, we have overarching suggestions for moving forward. In addition to our specific responses to EPA's charge questions, we have general guidance regarding the calculation of BAFs. 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. In the enclosed report, we offer an alternative formulation based on changes in terrestrial (non-atmospheric) carbon stocks (or pools) such as the live stocks in biomass, dead stocks, soil stocks, etc. that is more consistent with the principle of conservation of mass. An accounting system based on carbon stocks has multiple advantages: it is typically inventoried and modeled in the scientific community; it can be aggregated and rearranged as needed or further subdivided; and it will follow conservation of mass and is subject to mass balance. While this alternative formulation provides benefits, there still remain the issues of selecting appropriate temporal or spatial boundaries, considering variability within a class of feedstocks, accounting for non-CO_2 greenhouse gases such as nitrous oxide and methane, and quantifying stocks and fluxes that are difficult to measure or estimate. *Nonetheless, we conclude a BAF formulation based on carbon stocks is preferred over an emissions based approach.*

Using a carbon stock formulation, we show how to identify the time period (T) over which terrestrial (non-atmospheric) effects occur in response to increased harvesting of biomass for energy. On the overarching issues associated with choosing a temporal scale, the SAB acknowledges the difficult temporal questions associated with climate policy and the impacts on climate of shifting from fossil fuels to biogenic energy sources. Many considerations were appropriately raised by public commenters, including the uncertainties associated with future sequestration (carbon uptake); the possibility of tipping points, irreversibilities and feedback effects; and the need to provide incentives for technological change. These larger issues hinge on the value of emissions mitigation over time, an issue that lay above and beyond the scope of our charge. Our task was narrower: to provide the agency with feedback on how to adjust the BAF for sequestration and alternate fates (what carbon emissions might have happened had the feedstock not be used for energy). Nonetheless, since the impacts on climate of different emissions pathways are a valid consideration in climate policy, we gave it considerable thought in our 2012 report and again here. In the attached, we cite studies showing it is cumulative emissions over roughly a 100 year period that lead to a climate response and that different scenarios of emissions pathways over the next several decades that have equivalent cumulative emissions are likely to lead to remarkably little difference in global temperature response. So long as biomass is regrown repeatedly and appropriately substituted for future fossil fuels over successive harvest cycles, the use of biomass for energy need not imply greater net greenhouse gas emissions at longer time scales as compared to a business as usual scenario. *We conclude that the appropriate time scale for calculating a BAF is the time period over which all terrestrial effects occur; thus a cumulative BAF is scientifically appropriate.*

Using the carbon stock change formulation, we have also identified an alternative approach for calculating a cumulative BAF that attempts to account for the time path of the additional emissions in the atmosphere relative to a "business as usual" reference case. This alternative BAF approach accumulates the annual differences in carbon stocks on the land *over time* to account for the presence of carbon in the atmosphere each year. By contrast, EPA's cumulative BAF in the 2014 Framework accounts for the difference in carbon stocks *at the end of the time horizon*. Both cumulative BAFs are biophysical estimates that attempt to adjust biogenic emissions for sequestration and alternate fates. 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 EPA's cumulative BAF while the transitional effects on climate may be better captured by the alternative BAF offered in this report. An important issue when considering alternative cumulative BAFs is how to account for climate and carbon cycle uncertainties. *In sum, this report offers an alternative cumulative BAF to take into account changes in terrestrial carbon stocks over time, thus incorporating the time course of carbon emissions.*

Finally, EPA did not ask us for feedback on its modeling approach but given that alternative approaches can yield alternative results, we think this was an oversight. An integrated modeling approach that captures economic and biophysical dynamics and interactions is appropriate to simulate the "with" and "without" scenarios to estimate the additional effect of increased bioenergy demand on CO_2 emissions. While the 2014 Framework certainly employed such an integrated model for some of its alternative BAF calculations, EPA did not offer explicit justification for its modeling choices derived from articulated criteria. In addition, some underlying features of the model were unexamined. *Thus, we conclude EPA should identify and evaluate its criteria for choosing a model and examine the sensitivity of BAF estimates to these features.*

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

Sincerely,

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 Assessment Factor

BAU	Business As Usual
CH4	Methane
CO_2	Carbon Dioxide
CO_2e	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
USDA	U.S. Department of Agriculture

1. EXECUTIVE SUMMARY

The EPA requested the SAB to peer review a revised science-based framework for accounting for biogenic carbon emissions, which the agency 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] The EPA's November 2014 *Framework for Assessing Biogenic CO_2 Emissions from Stationary Sources* is a sequel to its 2011 Framework which the SAB reviewed in 2012. The goal of the 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.

Importance of the Policy Context

For its review of the 2011 Framework, 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 (PSD) air permit that were required to conduct a best available control technology (BACT) analysis 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 reaching 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 the EPA's charge questions seek general guidance on issues related to the choice of temporal, spatial and production scale for determining Biogenic Assessment Factors (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 multiple policy and implementation choices, others would have been more specific had such details been provided. A policy context would also be helpful in clarifying if the purpose of performing carbon accounting with the proposed Framework is to account for the emissions of all greenhouse gases that alter the climate. If this is the case, then it will be important to account for the effect of biogenic feedstocks on non-CO_2 gases such as N_2O and CH_4, and to examine how these effects differ across feedstocks and influence their BAF values.

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. In 2012, the SAB recommended a future anticipated baseline approach to capture the *additional* emissions created by any increased use of biomass for energy. The SAB's 2012 advice on the anticipated baseline approach recognized 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 increased bioenergy use. EPA's 2014 Framework employs a future anticipated baseline approach consistent with our earlier recommendations for some of its alternative BAF calculations. In the 2014 Framework, the

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

EPA has offered illustrative simulations of future biophysical and economic conditions employing the Forestry and Agricultural Sector Optimization Model (FASOM) to determine the incremental GHG emissions of increased biomass feedstock demand compared to a "business as usual" scenario. 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.

Modeling Approach

EPA did not ask for feedback on its modeling approach but, given that alternative approaches can yield alternative results, the choice of model is an important issue. For the task at hand, estimating BAFs, we believe that an integrated modeling approach that captures economic and biophysical dynamics and interactions is appropriate to simulate the "with "and "without" demand scenarios to estimate the additional effect of bioenergy demand on CO_2 emissions. Additionally, given the temporal scale of these impacts, the potentially wide choice of crop-based and forest feedstocks and the spatial heterogeneity in their production conditions, the dynamic model would need to include both the agricultural and the forestry sectors, competition between land using activities, investment decisions that consider potential future returns (especially for slower growing, long rotation feedstocks), and a large number of spatially distinct regions (while keeping the model tractable).

The FASOM model used by EPA for its illustrative BAF estimates in the 2014 Framework has the above features however there is a need for more model validation, evaluation, justification, and sensitivity analysis. Regardless of the model chosen, model validation and evaluation will be useful. Model validation is informative about the model's ability to replicate observed phenomenon at the starting point of the study period. Model evaluation can usefully elucidate the role of model features, such as spatial scope and resolution, linked agricultural and forest markets and land use change, economic dynamics (time frame, anticipatory planting/management), commodity resolution (where the ability to model feedstock types is affected), and biological dynamics (agricultural crops and productivity, forest biology, forest management practices) in influencing the BAF obtained. For example, a feature of intertemporal optimization models like FASOM, that could have implications for BAF estimates, is that landowners are assumed to make investment decisions based on expected current and future economic returns and engage in anticipatory planting and management if economical to do so given expected future biomass demand. This assumption could imply that an increase (decrease) in demand for biomass feedstocks translates into increased (decreased) investments in feedstock production that satisfy expected demand in the future. Accordingly, an increase in demand for a long-rotation feedstock may lead to a low BAF with the analytic assumption of long planning horizons. This assumption, along with other model features listed above, should be evaluated when justifying alternative modeling approaches; thus assessing the actual planning horizon of landowners is important. Other assumptions that should be examined include those related to productivity growth, soil carbon dynamics, the modeling of agriculture-forest land competition, and the disaggregation and characterization of biomass feedstocks. Over time, the model selected for estimating BAFs should be reviewed and updated periodically using observed changes in economic and land use conditions due to increased biomass demand, and the latest scientific information on biophysical and biogeochemical properties of feedstocks.

Alternate Fate Approach for Waste-Derived Feedstocks

In 2012, the SAB recommended that the EPA 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, the agency has conducted extensive alternate fate calculations (in Appendix N); however, the 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 scenarios. Specifically, the EPA neglected to recognize and quantify a potential alternate fate of MSW, in particular, current use in electrical energy recovery from both landfills and combustion. EPA also failed to consider carbon storage associated with landfills, and selected a landfill baseline that is inconsistent with regulatory practice. The relative rankings of BAF values across waste treatment options in the 2014 Framework would change considerably if current energy recovery uses were considered. The 2014 Framework clearly includes methane associated with municipal solid waste feedstocks but it omits current electrical energy recovery from both landfills and combustion as well as carbon storage associated with landfills. While we recognize that inclusion of electrical energy offsets would be inconsistent with the system boundaries described by EPA in the 2014 Framework, failure to account for these offsets has the potential to lead to inferior technology choices in consideration of all greenhouse gas emissions. In addition, when non-CO_2 greenhouse gases (such as methane) are a part of any projections of carbon emissions into the future, as may be the case for waste feedstocks, estimation of the BAF could be modified to account for the cumulative effect of these gases as with $CO_{2,}$. For example, the BAF could be modified to account for methane emissions for woody mill residuals.

Comments on Time Scale

Public commenters have pointed out the dangers of using a long time scale to assess the effects of long rotation feedstocks on the carbon cycle due to the uncertainties associated with future sequestration (carbon uptake); the possibility of tipping points, irreversibilities and feedback effects; and the need to provide incentives for technological change. These public comments highlight the intertemporal tradeoffs with the use of long rotation feedstocks where, in the short run, there can be a time lag between emissions (through combustion) and sequestration (through regrowth) with the use of forest biomass. At the landscape level, there can be concurrent debts and credits with harvesting and planting and in the short-run, debts can exceed credits before regrowth occurs. The use of forests as sinks (instead of for bioenergy) in the near term is advocated as a means to “buy time” and to avoid “tipping points” based on the expectation that these sinks can serve as temporary storage for carbon until new and cleaner technologies are developed to reduce carbon emissions.

The SAB’s comments on time scale for determining a BAF for a feedstock focus on accounting for all direct and indirect contributions of harvesting that feedstock for bioenergy on the atmosphere. This report does not address the impact of the magnitude and timing of those emissions on the climate system. Nonetheless, the value of emissions mitigation over time is relevant to the discussion of time scale and climate policy generally. On this topic, we have concluded that the harvesting of trees for bioenergy does not have to imply potential increased net greenhouse gas emissions at longer time scales if biomass is regrown repeatedly and substituted for future fossil fuels over successive harvest cycles. Reducing cumulative emissions can reduce the likelihood of tipping points in the future, while reducing emissions in the short run through temporary storage in forest sinks may at best delay tipping points by a few years but not reduce their likelihood in the longer term. We wish to underscore our caution that the net accumulation of forest and soil carbon over a long time scale (e.g. 100 years) should not be assumed to occur automatically or be permanent; rather growth and accumulation should be monitored and evaluated for changes resulting from management, market forces or natural causes.

Temporal Scale and the Future Anticipated Baseline Approach (Charge Question 1)

Charge question 1 and its subparts 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.

With respect to selecting a temporal scale, the most important criterion is whether it captures effects over time, i.e., the estimated terrestrial effects, both positive and negative, stemming from a change in the demand for biogenic feedstocks. Similar to the 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 however the same temporal scale should be used for all feedstocks to ensure comparability of their BAFs. We do not support changing the temporal scale to fit a policy horizon (the EPA's so-called "assessment horizon"); rather the time scale should be chosen to capture all effects and be the same across all feedstocks and all policies.

In view of the limitations of BAFs based on changes in carbon emissions, the SAB offers an alternative formulation based on the changes in carbon stocks on the land in contrast to the EPA's framework which is based on difference in carbon emissions. Our proposed alternative formulation (Appendix B) offers a prototype equation with terms for live stocks in biomass (i.e., stocks), dead stocks, soil stocks, product stocks and waste stocks. A key feature of using 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 B 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. While this alternative formulation provides benefits, there are still general issues of selecting appropriate temporal or spatial boundaries, considering variability within a class of feedstocks, accounting for non-CO_2 greenhouse gases such as nitrous oxide and methane, and quantifying stocks and fluxes that are difficult to measure or estimate.

In addition to offering a formulation based on carbon stocks, we illustrate an alternative cumulative BAF approach that attempts to take account of the time course of CO_2 emissions. This alternative metric accumulates the annual differences in carbon stocks on the land *during the entire time horizon*. In contrast, the EPA's cumulative BAF (which we designate as BAF_T) accounts for the difference in carbon stocks *at the end of the time horizon*. By cumulating annual differences across the entire projection period, the alternative cumulative BAF metric (which we designate as $BAF_{\sum T}$) incorporates "residence time" in the sense that it assumes the carbon stays in the atmosphere each year unless modified by changing stocks of carbon on the land. Mathematically, the $BAF_{\sum T}$ formulation implies a type of "ton-years" to account for changes in carbon stocks *year to year*.

The appropriate biophysical 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 $BAF_{\sum T}$. Consideration of the effect of timing of biogenic emissions on the climate hinges on the scientific assessment of the mechanisms by which carbon emissions affect global temperature, sea-level rise, oceanic uptake of carbon and other natural systems. These studies conclude that it is cumulative emissions over roughly a 100-year period that lead to a climate response and that different scenarios of emissions pathways over the next several decades that have equivalent cumulative emissions over the next 100 years are likely to lead to a similar global temperature response. Climate goals and carbon cycle dynamics and uncertainties (e.g., decay, uptake, feedbacks, and transient climate response) are important issues in considering the two cumulative BAFs.

Both cumulative BAFs attempt to capture and adjust biogenic carbon emissions for sequestration and alternate fates in a biophysical sense only. Neither metric provides information on the optimal path of mitigation over time. The SAB acknowledges the difficult questions raised by public commenters who pointed out the uncertainties associated with future sequestration (carbon uptake), the possibility of tipping points, irreversibilities and feedback effects and the need to provide incentives for technological change. We acknowledge these issues as valid considerations in climate policy, however our charge was narrower: how to adjust the BAF for sequestration and alternate fates.

Scales of Biomass Use and the Future Anticipated Baseline Approach (Charge Question 2)

Charge question 2 and its subparts was entirely devoted to very narrow 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 and specific BAF calculations. Some questions in this section would have been better framed by specifying a policy context that could be indicative of the likely scale of aggregate demand for biomass and could influence the methods for producing feedstocks. Noting these limitations, our responses are highlighted below.

The EPA asked for 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 Assessment Factor could be determined by the simulation model. In general, the BAF should be estimated for the average effect of the last increment of demand for biomass. To be consistent with reality, demand changes should be bounded by historical data on resource use, observed information on current and planned expansions to facilities using biogenic feedstocks, and reasonable projected cost-effective deployment of bioenergy consistent with the policy. Modeling exercises could also be undertaken to determine feedstock-specific 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 that determines the supply of a feedstock produced jointly with another crop with a market-determined demand. An analysis of the implications of assigning BAFs to feedstocks on the mix of feedstocks demanded and its ex-post implications for BAFs 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 projections about biomass demand could be revised based on actual outcomes. While a BAF may be calculated with a long period (e.g. 100 years), 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.

Summary of Major Conclusions and Recommendations

The 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, the 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 emissions associated with 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 calculating a BAF 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. Thus a cumulative BAF metric is appropriate.

3. The appropriate cumulative metric for calculating BAF will depend on the scientific assessment of mechanisms by which changes in atmospheric carbon stock affect the climate, with consideration of climate and carbon cycle uncertainties. An alternative cumulative BAF metric is offered in this SAB report that takes into account the changes in terrestrial carbon stocks *over time*, thus incorporating the time course of carbon emissions.

4. A BAF formulation based on changes in 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.

5. EPA should identify and evaluate its criteria for choosing a model and modeling features that affect BAF outcomes, including both model structure and assumptions about economic and biophysical parameters. EPA should also update and validate the model to incorporate the latest scientific knowledge while ensuring that the model outcomes are consistent with the observed reality.

2. INTRODUCTION

2.1. Background

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 CO_2 Emissions from Stationary Sources* (U.S. EPA 2014). 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 is to develop a method for calculating the adjustment, or Biogenic Assessment Factor (BAF), for CO_2 emissions associated with the use of biogenic feedstocks, taking into account the biological carbon cycle effects associated with their 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., wood mill 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 that reflects a biogenic feedstock's net carbon emissions after taking into account its sequestration of carbon, in biomass or soil, and so-called avoided emissions.

The 2014 Framework is a revision of the 2011 Framework (U.S. EPA 2011) which the SAB previously reviewed (U.S. EPA SAB 2012). To conduct the present 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. The panel held a face-to-face meeting 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 panel considered written and oral comments from members of the public. The panel's report was reviewed by the chartered SAB on [insert date].

2.2. Charge to the SAB

The EPA's charge to the SAB (Appendix A) requests advice and recommendations on its revised 2014 Framework, which was developed with consideration of the SAB's 2012 recommendations as well as the latest information and input from the scientific community and other stakeholders. The EPA asked the SAB to review and offer recommendations on specific technical elements of the 2014 Framework for assessing the extent to which the production, processing, and use of biogenic material at stationary sources results in a net atmospheric contribution of biogenic CO_2 emissions.

3. OVERARCHING COMMENTS

This section addresses issues that lie outside the scope of EPA's charge questions.

3.1. Policy Context

For its review of the 2011 Framework, 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 (PSD) air permit that were required to conduct a best available control technology (BACT) analysis 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 reaching 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 the EPA's charge questions 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 multiple policy and implementation choices, others would have been more specific had such details been provided. It also would have been useful to know more about the regulated entities that would be responsible for GHG emissions from biogenic feedstocks. 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 on the carbon cycle of using biogenic feedstocks.

In addition to the policy context, specific BAF calculations are also absent from the 2014 Framework. The 2014 Framework instead offers a large variety of possible BAF calculation options that suggest significant flexibility with all alternatives presented as equally legitimate. However, all these options are not scientifically equal and the 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 the EPA's regulatory authority. In the absence of these specifics, our report discusses in general terms the ways to address the temporal and spatial scale issues associated with estimating BAF values for different feedstocks.

A policy context would also be helpful in clarifying if the purpose of performing carbon accounting with the proposed Framework is to account for the emissions of all greenhouse gases that alter the climate. If this is the case, then it will be important to account for the effect of biogenic feedstocks on non-CO_2 gases such as N_2O and CH_4, and to examine how these effects differ across feedstocks and influence their BAF values. The 2014 Framework mentions that methane emissions from biogenic feedstocks are relatively small compared to those from other sources in the United States and also illustrates the implications of accounting for N_2O emissions for calculations of BAF. However, for many feedstocks, the global warming potential is greater from N_2O or CH_4 than from CO_2. For example non-CO_2 gases are particularly important for feedstocks grown with nitrogen fertilizer and for waste materials from landfills, as well as the development and delivery of fossil fuels to stationary sources, which would need to be considered for emissions accounting consistency across all fuel types. This issue was addressed previously by the SAB (U.S. EPA SAB 2012), however the EPA's response did not clarify their approach to account for such emissions from landfills and other biomass production, or associated fossil fuel activities, nor did it provide an adequate rationale for not acknowledging the importance of all GHG emissions in the Framework (U.S. EPA 2015). 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 substantial emissions of N_2O and/or CH_4.

Recommendation

- For proper scientific evaluation of a biogenic carbon accounting approach, the 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 emissions associated with a stationary facility. The Framework should be explicit about 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.

3.2. <u>Future Anticipated Baseline Approach</u>

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. The 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. The EPA has acknowledged this limitation in its 2014 Framework and now includes a future anticipated baseline analysis alternative along with a reference point approach. The SAB remains concerned that the reference point approach has important limitations and should not be the preferred approach.

The SAB's 2012 advice on the anticipated baseline approach recognized 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 increased 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, losses via decomposition, carbon sequestration and fluxes due to harvests and land use change and incorporates the spatial variability in these effects across the U.S.

Also consistent with our 2012 recommendations, the 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. The EPA initially considered calculating a 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 advance in its accounting methodology, we note some concern about factors that could be missed with overly-broad feedstock categories. In particular, the broad feedstock categories cited in the 2014 Framework (e.g., roundwood in the Southeast, logging residues in the Pacific Northwest, and corn stover in the Corn Belt) may not reflect extant or likely future variation in feedstock production or processing. Caution is advised that aggregation of feedstocks into such overly-broad categories may overlook important variation in management practices in feedstock production and in the treatment of waste in storage and transport. The EPA may wish to evaluate the "representativeness" of the factors and refine the approach over time.

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 (then and now) 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, the EPA has offered illustrative simulations of future biophysical and economic conditions employing the Forestry and Agricultural Sector Optimization Model (FASOM) to determine the incremental GHG emissions of increased biomass feedstock demand compared to a "business as usual" scenario. 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. Instead, the EPA posed very narrow technical 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.

3.3. <u>Modeling Approach</u>

The EPA did not ask for feedback on its modeling approach but, given that alternative approaches can yield alternative results, we think this was an oversight. For greater public confidence in results, there is, in general, a need for more model validation, evaluation, justification, and sensitivity analysis. Model validation and evaluation will help the public understand model behavior and sensitivity. Explicit justification for the modeling approach derived from articulated criteria and discussion of alternatives will give the public greater confidence in the approach chosen. And, well-designed sensitivity analysis that captures BAF sensitivity and uncertainty will help establish the robustness of estimates and legitimacy of the BAF values used.

Some have criticized the use of economic models for assessing future carbon stocks and flows. Economic approaches assume there are human responses to market forces, such as changes in land use, land management, and production in response to an increased demand for biomass for energy. Alternative approaches that solely focus on the physical ecosystem ignore market implications and human management responses but economic and ecological models can complement each other. For example, certain biomass feedstocks—such as invasive plant species, beetle-infested trees, biomass cleared to reduce threat of wildfires, and forest thinnings—may become available to reduce other environmental harms such as biodiversity loss and forest fires and loss of ecosystem services. Since the availability of these types of biomass depends largely on biophysical factors rather than economic factors, greater reliance on ecological models may be necessary to determine the supply of biomass from such sources. Additionally, it may be appropriate to consider the alternative fate of these sources of bioenergy in determining their BAF. Harvesting biomass that might otherwise invite forest fires has a prevention benefit that would have to be weighed against any smokestack emissions that might occur at a facility from combusting such biomass.

For the task at hand, estimating BAFs, an integrated modeling approach (one that captures economic and biophysical dynamics and interactions) should be used to simulate the "with "and "without" bioenergy demand scenarios to estimate the additional effect of bioenergy demand on CO_2 emissions. Additionally, given the temporal scale of these impacts, the potentially wide choice of crop-based and forest feedstocks and the spatial heterogeneity in their production conditions, the dynamic model would need to include both the agricultural and the forestry sectors, competition between land using activities, investment decisions that consider potential future returns (especially for slower growing, long rotation feedstocks), and a large number of spatially distinct regions (while keeping the model tractable). The Forestry and Agricultural Sector Optimization Model (FASOM) used by the EPA for its illustrative BAF estimates in the 2014 Framework has the above features.

Regardless of the model chosen, model validation and evaluation is needed. Model validation is informative about the model's ability to replicate observed phenomenon at the starting point of the study period. Model evaluation can usefully elucidate the role of model features, such as spatial scope and resolution, linked agricultural and forest markets and land use change, economic dynamics (time frame, anticipatory planting/management), commodity resolution (where the ability to model feedstock types is affected), and biological dynamics (agricultural crops and productivity, forest biology, forest management practices) in influencing the BAF obtained. For example, a feature of intertemporal optimization models like FASOM, that could have implications for BAF estimates, is that landowners are assumed to make investment decisions based on expected current and future economic returns and engage in anticipatory planting and management if economical to do so given expected future biomass demand. This assumption could imply that an increase (decrease) in demand for biomass feedstocks translates into increased (decreased) investments in feedstock production that satisfy expected demand in the future. Accordingly, an increase in demand for a long-rotation feedstock may lead to a low BAF with the analytic assumption of long planning horizons. Wang et al. (2015) have shown that a key determinant of the impact of demand for bioenergy on forest carbon stock is the assumption about the length of planning horizon of forest landowners. Wang et al. (2015) further showed significantly lower carbon storage in forests with an assumption of a 15 year planning horizon compared to a 50 year planning horizon. This assumption, along with other model features listed above, should be evaluated when justifying alternative modeling approaches; thus assessing the actual planning horizon of landowners is important. Other assumptions that should be examined include those related to productivity growth, soil carbon dynamics, the modeling of agriculture-forest land competition, and the disaggregation and characterization of biomass feedstocks.

Model evaluation will also usefully inform sensitivity analysis and uncertainty characterization. The latter includes model parameter and model selection (i.e., structure) uncertainty. The models should be sensitive to certain driving variables and processes. The EPA's approach should be able to provide some estimate of uncertainty. Sensitivity of the BAF to modeling assumptions and modeling structure should be evaluated to assess the robustness of the BAF estimates and to identify those features of the model that can significantly affect outcomes and, therefore, need close scrutiny to determine their reliability. Sensitivity analysis could also be used to determine the extent to which different production methods for a feedstock lead to meaningful differences in BAF estimates and therefore should be delineated. An uncertainty analysis may also be conducted, if feasible, to determine the plausible range of BAF estimates for a feedstock and to assess the relative confidence in the accuracy of the point estimate of a BAF assigned to a feedstock.

Finally, over time, the model selected for estimating BAFs should be reviewed and updated using observed changes in economic and land use conditions due to increased biomass demand, and the latest scientific information on biophysical and biogeochemical properties of feedstocks.

Recommendations

- The EPA should identify and evaluate its criteria for choosing a model and modeling features that affect BAF outcomes, including both model structure and assumptions about economic and biophysical parameters. In addition, the EPA should periodically update and validate the model to incorporate the latest scientific knowledge while ensuring that the model outcomes are consistent with the observed reality.

3.4. Alternate Fate Approach for Waste-Derived Feedstocks

Although there were no charge questions on the alternate fate approach for waste-derived feedstocks, we address it here because of its importance. In 2012, the SAB recommended that the EPA consider the alternate fate (i.e., if not used as fuel) 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, the EPA has conducted extensive alternate fate calculations in Appendix N; however, the agency drew a narrow boundary around point source emissions and neglected other significant considerations that affect the GHG footprint of alternative municipal solid waste (MSW) management scenarios. Specifically, the EPA neglected to recognize and quantify a potential alternate fate of MSW, in particular, current use in electrical energy recovery from both landfills and combustion. EPA also neglected to quantify carbon storage associated with landfills, and selected a landfill baseline that is inconsistent with regulatory practice. 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 of BAF values across waste treatment options in the 2014 Framework would change considerably if current energy recovery uses were considered. The 2014 Framework clearly includes methane associated with municipal solid waste feedstocks, while neglecting to quantify current electrical energy recovery from both landfills and combustion, and neglecting to quantify carbon storage associated with landfills. While we recognize that inclusion of electrical energy offsets would be inconsistent with the system boundaries described by EPA in the 2014 Framework, failure to account for these offsets has the potential to lead to inferior technology choices in consideration of all GHG emissions. In addition, when non-CO_2 greenhouse gases (such as methane) are a part of any projections of carbon emissions into the future, as may be the case for waste feedstocks, estimation of the BAF could be modified to account for the cumulative effect of these gases as with CO_2. One public commenter provided an example showing the effect on BAF of incorporating methane emissions for woody mill residuals (National Council for Air and Stream Improvement 2015).

3.5. Comments on Time Scale

Public commenters have pointed out the dangers of using a long time scale to assess the effects of long rotation feedstocks on the carbon cycle due to the uncertainties associated with future sequestration (carbon uptake); the possibility of tipping points, irreversibilities and feedback effects; and the need to provide incentives for technological change. These public comments highlight the intertemporal tradeoffs with the use of long rotation feedstocks where, in the short run, there can be a time lag between emissions (through combustion) and sequestration (through regrowth) with the use of forest biomass. At the landscape level, there can be concurrent debts and credits with harvesting and planting and in the short-run debts can exceed credits before regrowth occurs. Some public commenters advocated the use of forests as carbon sinks (instead of for bioenergy) in the near term as a means to “buy time” and to avoid “tipping points” based on the expectation that these sinks can serve as temporary storage for carbon until new and cleaner technologies are developed to reduce carbon emissions.

The SAB’s comments on time scale for determining a BAF for a feedstock focus on accounting for all direct and indirect contributions of harvesting that feedstock for bioenergy on the atmosphere. Our comments are not based on the impact of those emissions on the climate system. Nonetheless, the value of emissions mitigation over time is relevant to the discussion of time scale and climate policy generally. Thus we wish to address the concerns of some public commenters who generally favored short-run emissions mitigation over long-run mitigation. The following discussion builds on our previous comments (U.S. EPA SAB 2012).

Consideration of the effect of timing of biogenic emissions on the climate hinges on the scientific assessment of the mechanisms by which carbon emissions affect global temperature, sea-level rise, oceanic uptake of carbon and other natural systems. A number of existing studies (Allen et al. 2009; Matthews et al. 2009) find that the relationship between carbon emissions and their impact on the climate is not linear or immediate. These studies conclude that it is cumulative emissions over roughly a 100-year period that lead to a climate response and that different scenarios of emissions pathways over the next several decades that have equivalent cumulative emissions over the next 100 years are likely to lead to a similar global temperature response. Similarly, Kirschbaum (2006) finds virtually no climate benefit for sinks established in the near term (next several decades).

What this means is that an intervention in forests or farming that results in either an increase or decrease in storage of carbon or emissions reductions must endure significantly longer than 100 years to have an influence on the peak climate response as long as cumulative emissions from all sources are constant. Conversely, if these changes last less than 100 years, harvesting of biomass for bioenergy resulting in release of carbon dioxide will have a relatively small effect on peak warming. While the harvesting of trees for bioenergy could result in a carbon debt even at the landscape level (Mitchell et al. 2012), this may not imply increased greenhouse gas emissions at longer time scales if biomass is regrown repeatedly and appropriately substituted for future fossil fuels over successive harvest cycles (Galik and Abt 2012). Kirschbaum (2003) also found that a short-rotation plantation used repeatedly for bioenergy that would displace future fossil fuels would provide a similar climate change mitigation benefit over a 100-year period as forests maintained permanently. On the other hand, continuing use of fossil fuels due to delays in their displacement by biogenic carbon is likely to result in higher cumulative emissions in the atmosphere in the long run. Cherubini et al. (2012) have also shown that if biomass is harvested and regrown in successive cycles within a 100-year time scale, the global average temperature increase over that 100-year period is 50% of the temperature increase caused by an equivalent amount of fossil carbon. (For additional discussion of the implications of Cherubini et al. (2012), see Appendix B of U.S. EPA SAB 2012.)

Sea-level rise over the next few decades also is not connected to the trajectory of emissions in the next few decades; instead it depends on the overall trend in global temperatures (which in turn depends on cumulative emissions over a 100-year period) and the integration of warming effects over the long run. Reducing cumulative emissions will reduce the likelihood of crossing tipping points or thresholds in the climate system in the future, while reducing emissions in the short run through temporary storage in forest sinks may at best delay tipping points by a few years but not reduce their likelihood in the longer term.

For climate policy generally, the BAF is not the best policy tool for internalizing the external cost of carbon to reduce greenhouse gases on any time scale. In fact, economic research has shown that the most cost-effective way to reduce GHG emissions is to impose a price on carbon across all sources, whether fossil or biogenic, a policy option that lies outside the EPA's regulatory authority. Likewise, it would be appropriate to account for the full life cycle emissions and not just the biogenic carbon cycle impacts. Nonetheless, in recognition of the temporal issues associated with biogenic feedstocks in the context of the EPA's regulatory authority over stationary sources, the SAB offers an alternative (in section 4.1). BAF formulation that places more emphasis on transitional or short-run effects ($BAF_{\sum T}$) while also acknowledging the validity of a metric that captures cumulative emissions at some point in the future (BAF_T).

Finally we underscore our caution that the net accumulation of forest and soil carbon over a 100-year period should not be assumed to occur automatically or to be permanent; rather, growth and accumulation should be monitored and evaluated for changes resulting from management, market forces or natural causes.

4. RESPONSES TO EPA'S CHARGE QUESTIONS

4.1. 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 CO_2 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 and short- and long-term soil carbon changes on the land. These effects may work on different temporal scales across feedstocks. Nevertheless, we recommend that the same time scale should be used for all feedstocks to determine their BAF in order to ensure comparability of BAFs across feedstocks. Additionally, the longest of these time scales as measured for any feedstock production system could be used as 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 the EPA, this "emissions horizon" is the period of time during which the carbon fluxes resulting from actions taking place today actually occur …" (U.S. EPA 2014). 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 when 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. The time horizon could be standardized by selecting the longest time period among the various feedstock horizons and applying it to all feedstocks.

Recommendation

- The appropriate time scale for calculating a BAF 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. Thus a cumulative BAF metric is appropriate.

Charge Question 1(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 for scientific consideration of carbon stock changes should be chosen to capture all effects on carbon stocks, thus it should not vary by policy or landscape conditions.

Charge Question 1(a)(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 should 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.

Charge Question 1(a)(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.

Charge Question 1(a)(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.

Charge Question 1(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 (both short-term and long-term) should be considered 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. The policy horizon should include all changes in carbon stocks that occur during the emissions horizon.

Charge Question 1(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 feedstock over a time horizon is preferred to a marginal or instantaneous ("per period") BAF. (For the purposes of answering this question, the SAB interprets "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 of biomass.)

We note that the 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 metric 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 stocks on the land and in water. Since carbon that is not stored on the land is emitted to the atmosphere, conservation of mass dictates that any carbon taken from the land (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 and use of feedstocks in ways that fall outside the scope of the policy.

The use of biogenic feedstocks can affect the time sequence of emissions in the policy scenario relative to the time sequence of emissions in the reference case, and each affects the time sequence of terrestrial carbon stocks. 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 determines the time path of carbon changes on the land.

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. This might be more properly phrased "what the atmosphere initially sees." Neither the EPA's framework nor any modifications we offer take into account the decay of carbon molecules in the atmosphere over time or oceanic uptake of carbon. Thus all BAF calculations are based only on "debits" or tons of carbon added to the atmosphere, rather than any "credits" associated with atmospheric decay or oceanic uptake. Considering the sum of 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 more fully the effect of the use of biogenic feedstocks over a time period. Denoted as $BAF_{\sum T}$, this modification to the 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. This modification to the BAF formula, as explained further below, would yield something like "ton-years" to account for differences in carbon stocks *each year*.

To answer the question of what emissions the atmosphere initially receives, the SAB suggests an alternative formulation for biogenic carbon accounting (discussed in more detail in Appendix B) that is based on changes in carbon stocks between a policy case and a reference case rather than on differences in carbon fluxes. A key feature of using carbon stocks is that all terms can be readily aggregated or disaggregated and are still subject to mass balance.

We define net biogenic emissions (NBE) aggregated over time as:

$$NBE_{\sum T} = \sum_{t=0}^{T} (TC_{Reference}(t) - TC_{Policy}(t)) \quad \text{(Eq. 1)}$$

Where:

$TC_{policy}(t)$ = the total stock of land carbon in the policy scenario in year *t* with increased demand for a biogenic feedstock; and

$TC_{Reference}(t)$ = the total stock of land carbon in the reference scenario in year *t*.

While our anticipated baseline approach is consistent with the EPA's, $BAF_{\sum T}$ would accumulate the annual differences in carbon stocks on the land, which accounts for the time path of net difference in CO_2 emissions over time. To do this, NBE and potential gross emissions (PGE) would reflect the differences in carbon stocks between the policy scenario and the reference scenario. We can interpret $NBE_{\sum T}$ 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 $BAF_{\sum T}$ ratio.

The denominator of the $BAF_{\sum T}$ 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_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 term 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:

$$PGE_{\sum T} = \sum_{t=0}^{T} PGE_t \quad \text{(Eq. 2)}$$

We now define $BAF_{\Sigma t} = \frac{NBE_{\Sigma T}}{PGE_{\Sigma T}}$ for a given time horizon T. (Eq. 3)

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 $NBE_{\sum T}$. 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 could also be used for all other feedstocks to allow for comparability.

We illustrate this $BAF_{\sum T}$ value graphically in Appendix C and Appendix D in different cases. These cases provide examples with carbon stocks 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 (U.S. EPA 2014). EPA's cumulative BAF in the 2014 Framework is based on the difference in emissions between the reference scenario and the policy scenario as follows:

$$NBE_t = \sum_{t=0}^{T} \Delta TC_{Reference}(t) - \Delta TC_{Policy}(t) = \mathrm{TC}_{Reference}(T) - TC_{Policy}(T) \qquad \text{(Eq. 4)}$$

where ΔTC is the change in carbon stocks at time t relative to $t\text{-}1$ 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 $t=0,\ldots T$. The 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.

$$\Delta TC_{Reference}(t) - \Delta TC_{Policy}(t) \qquad \text{(Eq. 5)}$$

$$BAF_{\Delta t} = \frac{\Delta TC_{Reference}(t) - \Delta TC_{Policy}(t)}{PGE_{\Delta t}} \qquad \text{(Eq. 6)}$$

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 also are 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 $\mathrm{BAF}_{\sum T}$ framework, a general rule to determine T is when the $\mathrm{NBE}_{\Delta t}$ asymptotes. In many cases, $\mathrm{NBE}_{\Delta t}$ 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., net primary productivity) that continue longer than the "assessment" window, then it is possible for the $\mathrm{NBE}_{\Delta t}$ 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 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 depend on external changes in the environment that change the productivity of both scenarios. There is no scientific way to determine after this point (i.e., when $\mathrm{NBE}_{\Delta t}$ 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 the EPA will need to make a policy decision as to whether the BAF used will be assumed to account for just the period up to T or to extend beyond that period to include the interaction of environmental changes and the policy scenario. Another consideration is that the error bounds on predictions of $\mathrm{NBE}_{\Delta t}$ will increase with t (indicated by sensitivity tests) and could eventually include zero. This result would indicate one could no longer accept the hypothesis that there is a change in difference in land carbon 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 different measures of BAF can lead to widely different values for any particular case. For the range of examples we present, $BAF_{\sum T}$ 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 $BAF_{\sum T}$; i.e., one that 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 the 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 GHG 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 employs two assumptions: (1) it assumes feedstock regrowth following an assumed rotation length; and (2) it assumes 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 the latest data and trends. 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, using data from existing inventory programs, and thus 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 they becomes available.

Recommendations

- The SAB recommends a BAF formulation based on changes in carbon stocks (terrestrial pools such as live, dead, soil, products, material lost in transport and waste), rather than 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.

- The SAB suggests an alternative cumulative BAF metric to take into account the changes in terrestrial carbon stocks over time, thus incorporating the time course of carbon emissions. The appropriate cumulative metric 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.

Charge Question 1(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?

It is appropriate to periodically revise the modeling and BAF estimates, but not too frequently so as to provide regulatory stability. The goal would be to update underlying economic and biophysical assumptions and modeling trends in light of new data. An update would require a review of current model assumptions and outputs relative to observations and new scientific knowledge.

A retrospective comparison would compare model projected behavior to newly available historical observations and estimates, such as regional feedstock demand, land use changes (e.g., afforestation and conversion of land to dedicated energy crops), and forest carbon measurements and estimates (both level and composition). To the extent that there are differences between modeled and observed metrics it would be practical to re-examine parameters, functional forms and other assumptions of the modeling approach. However, caution is merited. Observations, for example of land use and land management change, are the result of many factors and drivers, including potentially increased biomass demand. The goal of an ex post evaluation should be to make adjustments to the key parameters, functional forms and assumptions that can be improved with hindsight, thus improving the estimated 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 change), but also changes in management intensity, forest rotations and other forest dynamics. (For additional comments on the EPA's modeling approach, see section 3.2.)

4.2. 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?

Charge Question 2(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?
Charge Question 2(b). What should the general increment of the shock be? Should it be specified in tons, or as a percentage increase?

We have combined our responses to questions 2(a) and 2(b) because both questions relate to the size of the simulated "shock" in biomass feedstock demand.

If the 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 level of increased aggregate (national-level) demand for biomass to determine the mix of feedstocks and the quantity of each feedstock likely to be demanded, and 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 could result in multiple BAFs for a feedstock due to the diversity in production practices in a given region, rather than a single BAF; this could be used to define an upper and lower bound to the BAF and provide incentive for facilities to achieve the lower bound BAF.

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 separately for each feedstock in a region determined above as the change in demand for those feedstocks alone relative to the reference case; or (2) increasing demand separately for each feedstock 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; the latter approach would serve 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 on carbon emissions of the marginal increase in demand for feedstocks in a region while taking into account its effect on all other regions. BAFs calculated for the marginal impact of the last increment could be used to provide the appropriate signal of the carbon impact of using one more incremental 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.

Charge Question 2(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 a scenario without increased demand for biogenic feedstock use, the reference case should be one with no or limited demand for biomass. 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 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 based on the average effect of the last increment of biomass above the reference case that includes the increased usage of the feedstock. The average value of the BAF of the last increment 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; 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)—towards those with relatively lower BAFs in a region. It may not be appropriate to assign different BAF values to different methods of producing a feedstock if a sensitivity evaluation indicates the BAF estimates are not significantly different.

Charge Question 2(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 categorys)?

Charge Question 2(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 combined our responses to questions 2(d) and 2(e) because both questions 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 be used to determine demand for different feedstocks in different regions endogenously by the model. This would endogenously allocate demand across feedstocks as well as within each category to simulate a given target aggregate demand determined by the market's ability to draw from the least cost combination of feedstocks.

A joint production function is relevant for feedstocks like corn stover (which is driven by corn production) and forest residue (which is driven by saw timber 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 of those feedstocks to be produced while recognizing the practical limits on demand for the primary product. This approach 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.

Charge Question 2(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 would likely vary by the scale of demand. In fact, a single set of default BAFs is unlikely to 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 there is a 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.

Charge Question 2(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 when generating policy neutral default factors and factors tied to a specific policy. The only differences would be that (1) 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 a specific policy, 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 (2) 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 and its consequences for CO_2 emissions can be attributed to a specific policy (when there are multiple policies inducing a shift to renewable energy) is likely to be complicated and challenging to convert into policy-specific BAFs. It could also create perverse incentives for feedstock choice to comply with various policies.

Charge Question 2(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 until the ex-ante and the modeled ex-post solutions converge.

An ex post evaluation would also allow revisions to the 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.

REFERENCES

Allen, M. R., Frame, D. J., Huntingford, C., Jones, C. D., Lowe, J. and Meinshausen, M. (2009). Warming Caused by Cumulative Carbon Emissions toward the Trillionth Tonne. *Nature* 1163 - 1166.

California Air Resources Board. (2014). *Compliance Offset Protocol, U.S. Forest Projects.* Retrieved from http://www.arb.ca.gov/regact/2014/capandtrade14/ctusforestprojectsprotocol.pdf.

Cherubini, F., Guest, G. and Stromman, A. (2012). Application of Probability Distributions to the Modeling of Biogenic CO2 Fluxes in Life cycle Assessment. *Global Change Biology Bioenergy* 1 - 15.

Galik, C.S. and Abt. R.C. (2012). The effect of assessment scale and metric selection on the greenhouse gas benefits of woody biomass. *Biomass and Bioenergy* 44:1–7.

Hoover, C., Birdsey, R., Goines, B., Lahm, P., Marland, G., Nowak, D., . . . Woodall, C. (2014). *Quantifying Greenhouse Gas Fluxes in Agriculture and Forestry: Methods for Entity-Scale Inventory.* Retrieved from http://www.usda.gov/oce/climate_change/Quantifying_GHG/Chapter6S.pdf.

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

Kirschbaum, M.U.F. (2003). Can Trees Buy Time? An Assessment of the Role of Vegetation Sinks as Part of the Global Carbon Cycle. *Climatic Change* 58: 47-71.

Kirschbaum, M.U.F. (2006). Temporary Carbon Sequestration Cannot Prevent Climate Change. *Mitigation and Adaptation Strategies for Global Change* 11: 1151-1164.

McCabe, J. G. (2014). *Addressing Biogenic Carbon Dioxide Emissions from Stationary Sources*. Memo to Air Divison Directors, Region 1 – 10. Retrieved from http://www.epa.gov/climatechange/downloads/Biogenic-CO_2-Emissions-Memo-111914.pdf.

Matthews, H.D., Gillett, N.P., Stott, P.A. and Zickfeld, K. (2009). The proportionality of global warming to cumulative carbon emissions. Nature (Vol. 459). doi:10.1038/nature08047: 829-832.

Mitchell, S.R., Harmon, M.E. and O'Connell, K.E.B. (2012). Carbon debt and carbon sequestration parity in forest bioenergy production. *Global Climate Change Bioenergy*, doi: 10.1111/j.1757-1707.2012.01173.x

National Council for Air and Stream Improvement. (2015). Comment to the Biogenic Carbon Emissions Panel of the EPA Science Advisory Board. August 5, 2015. Retrieved from http://yosemite.epa.gov/sab/sabproduct.nsf/254A0104C4745E5785257E98006493E4/$File/NCASI+comments+for+Aug.+6,+2015.pdf

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

Ogle, S. P. (2014). *Chapter 3: Quantifying Greenhouse Gas Sources and Sinks in Cropland and Grazing land Systems. In Quantifying Greenhouse Gas Fluxes in Agriculture andForestry: Methods for Entity-Scale Inventory.* Vol. Technical Bulletin Number 1939. (U. S. Office of the Chief Economist, Ed.) Washington, DC. Retrieved from http://www.usda.gov/oce/climate_change/Quantifying_GHG/Chapter3S.pdf.

U.S. EPA (Environmental Protection Agency). (2011). *Accounting Framework for Biogenic CO_2 Emissions from Stationary Sources.* Office of Atmospheric Programs. Retrieved from http://www.epa.gov/climatechange/Downloads/ghgemissions/Biogenic-CO2-Accounting-Framework-Report-Sept-2011.pdf.

U.S. EPA (Environmental Protection Agency). (2014). *Framework for Assessing Biogenic CO_2 Emissions from Stationary Sources.* Retrieved from http://www.epa.gov/climatechange/ghgemissions/biogenic-emissions.html.

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

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

Wang, W., Dwivedi, P. Abt, R. and Khanna, M. (2015). Carbon Savings with transatlantic trade in pellets: accounting for market-driven effects. *Environmental Research Letters.* 10 , 114019; doi:10.1088/1748-9326/10/11/114019

Appendix A: Charge to the SAB

February 25, 2015

<u>MEMORANDUM</u>

To: **Holly Stallworth, Designated Federal Official**
Science Advisory Board Staff Office

From: **Paul Gunning, Director**
Climate Change Division

Subject: **Framework for Assessing Biogenic CO_2 Emissions from Stationary Sources and Charge Questions for SAB peer review**

The purpose of this memorandum is to transmit the revised *Framework for Assessing Biogenic CO_2 Emissions from Stationary Sources*, related documentation and charge questions for consideration by the Science Advisory Board (SAB) during your upcoming peer review.

In January 2011, the U.S. Environmental Protection Agency (EPA) announced a series of steps it would take to address biogenic CO_2 emissions from stationary sources. EPA committed to conduct a detailed examination of the science and technical issues related to assessing biogenic CO_2 emissions from stationary sources and to develop a framework for evaluating those emissions. The draft study was released in September 2011 and subsequently peer reviewed by the SAB Ad-Hoc Panel on Biogenic Carbon Emissions (SAB Panel). The final peer review report was published September 2012.

To continue advancing the agency's technical understanding of the role that biomass use can play in reducing overall greenhouse gas emissions, the EPA released a second draft of the technical report, *Framework for Assessing Biogenic Carbon Dioxide for Stationary Sources*, in November 2014. This revised report presents a methodological framework for assessing the extent to which the production, processing, and use of biogenic material at stationary sources results in a net atmospheric contribution of biogenic CO_2 emissions. The revised report takes into account the SAB Panel's peer review recommendations on the draft 2011 Framework as well as the latest information and input from the scientific community and other stakeholders.

The revised framework addressed many of the SAB Panel's key concerns and recommendations by incorporating: an anticipated baseline approach analysis, including an alternative fate approach for waste-derived feedstocks and certain industrial processing products and byproducts; an evaluation of tradeoffs from using different temporal scales; an improved representation of the framework equation; and illustrative case studies demonstrating how the framework equation can be applied, using region-feedstock combinations to generate regional defaults per different baseline approaches and temporal scales.

We ask the SAB to review and offer recommendations on specific technical elements of the revised framework for assessing the extent to which the production, processing, and use of biogenic material at stationary sources results in a net atmospheric contribution of biogenic CO_2 emissions, as identified in the charge accompanying this memo. We look forward to the SAB's review.

Please contact me if you have any questions about the attached study and charge.

Attachments:

1) *Framework for Assessing Biogenic CO_2 Emissions from Stationary Sources*
2) Technical Appendices
3) Response to the 2011 SAB Panel Peer Review Advisory

Peer Review Charge on the Framework for Assessing Biogenic CO_2 Emissions from Stationary Sources

To improve the quality, utility, and scientific integrity of the Framework, EPA is providing this study, *Framework for Assessing Biogenic CO_2 Emissions from Stationary Sources* (November 2014) and related materials to the Science Advisory Board (SAB). The revised report takes into account the SAB Biogenic Carbon Emissions Panel's ("SAB Panel") peer review recommendations[2] on the draft 2011 Framework[3] as well as the latest information and input from the scientific community and other stakeholders. The "Response to SAB" document included in the materials provided for this review discusses and responds to the SAB Panel key points and recommendations, serving as a guide to how the revised framework incorporates their recommendations. This charge narrowly focuses on a few specific remaining questions that were not explicitly addressed in the initial SAB Panel peer review report.

The revised 2014 framework report identifies key scientific and technical factors associated with assessing biogenic CO_2 emissions from stationary sources using biogenic feedstocks, taking into account information about the carbon cycle. It also presents a methodological framework for assessing the extent to which the production, processing, and use of biogenic material at stationary sources for energy production results in a net atmospheric contribution of biogenic CO_2 emissions.

The revised framework and the technical appendices address many of the SAB Panel's key concerns and recommendations by incorporating: an anticipated baseline approach analysis (Appendices J-L); an alternative fate approach for waste-derived feedstocks (Appendix N); and certain industrial processing products and byproducts (Appendix D Addendum); an evaluation of tradeoffs from using different temporal scales (Appendix B); an improved representation of the framework equation (Appendix F); and illustrative case studies demonstrating how the framework equation can be applied, using region-

[2] The final peer review report from the SAB Panel on the draft 2011 framework was published on September 28, 2012 (Swackhamer and Khanna, 2011). Information about the SAB peer review process for the September 2011 draft framework is available at http://yosemite.epa.gov/sab/sabproduct.nsf/0/2F9B572C712AC52E8525783100704886.

[3] The 2011 *Draft Accounting Framework for Biogenic CO_2 Emissions from Stationary Sources* is available at www.epa.gov/climatechange/ghgemissions/biogenic-emissions.html.

feedstock combinations to generate regional defaults per different baseline approaches and temporal scales (Appendices H-N).

As explained in the revised framework introduction and accompanying SAB response document, the revised framework maintains the policy neutral approach from the 2011 draft Framework. It is a technical document that does not set regulatory policy nor does it provide a detailed discussion of specific policy and implementation options. Ultimately, the framework provides a methodological approach for considering, and a technical tool (the framework equation) for assessing, the extent to which there is a net atmospheric contribution of biogenic CO_2 emissions from the production, processing, and use of biogenic material at stationary sources. The revised framework details technical elements that should be considered as appropriate per specific policy applications or biogenic carbon-based feedstock assessments. Therefore, this charge excludes policy and regulatory recommendations or legal interpretation of the Clean Air Act's provisions related to stationary sources.

The revised report does not provide any final values or determinations: it offers indications of different biogenic feedstock production effects per research and analyses conducted, including illustrative example results per specific case study parameters. As discussed by the previous SAB Panel, this report also finds that biophysical and market differences between feedstocks may necessitate different technical approaches. Even using a future anticipated baseline approach, forest- and agriculture-derived feedstock characteristics, and thus analyses and results, may vary per region and per feedstock, and may be influenced by land use change effects. Illustrative analyses conducted for specific waste-derived feedstock case studies using a counterfactual anticipated baseline, as recommended by the SAB Panel, yielded minimal or negative net emissions effects.

This charge focuses on questions that remain regarding whether there are more definitive technical determinations appropriate for parameterizing key elements of the revised framework, regardless of application to a specific policy or program. Specifically, we ask that the SAB Panel examine and offer recommendations on future anticipated baseline specification issues in the context of assessing the extent to which the production, processing, and use of forest- and agriculture-derived biogenic material at stationary sources for energy production results in a net atmospheric contribution of biogenic CO_2 emissions – such as appropriate temporal scales and the scale of biogenic feedstock usage (model perturbations or 'shocks') for analyzing future potential bioenergy production changes.

Technical approaches, merits and challenges with applying a future anticipated baseline

Establishing a baseline creates a point of comparison necessary for evaluating changes to a system.[4] Baseline specification can vary in terms of what entity or groups of entities are being analyzed (e.g., industries, economic sectors), temporal and spatial scales, geographic resolution, and, depending on context, environmental issues/attributes (EPA, 2010).[5] The choice of baseline approach can also depend on the question being asked and the goal of the analysis at hand. For example, some GHG analysis may

[4] Definitions for baseline vary, including "the reference for measurable quantities from which an alternative outcome can be measured" (IPCC AR4 WGIII, 2007) or "the baseline (or reference) is the state against which change is measured. It might be a 'current baseline,' in which case it represents observable, present-day conditions. It might also be a 'future baseline,' which is a projected future set of conditions excluding the driving factor of interest. Alternative interpretations of the reference conditions can give rise to multiple baselines" (IPCC AR4 WGII, 2007).

[5] Guidelines for Preparing Economics Analyses (NCEE), Chapter 5: http://yosemite.epa.gov/ee/epa/eerm.nsf/vwAN/EE-0568-05.pdf/$file/EE-0568-05.pdf

require a baseline against which historic changes of landscape carbon stocks can be measured. Other applications may necessitate a baseline against which the estimated GHG emissions and sequestration associated with potential future changes in related commodity markets and policy arenas. Analyses of the estimated GHG emissions and sequestration effects from changes in biomass use have used different baseline approaches, as well as a wide range of different temporal scales and alternative scenario parameters (Sohngen and Sedjo, 2000; Fargione, 2008; UNFCCC, 2009; Walker et al., 2010; Cherubini et al, 2011; Galik and Abt, 2012; Latta et al., 2013; Walker et al., 2013; AEO, 2014; U.S. EPA, 2014; Miner et al., 2014).

The draft 2011 framework had discussed three different potential baseline approaches – reference point, future anticipated and comparative – and used the reference point baseline in its hypothetical case study applications of the Framework. The SAB Panel in its review stated that "the choice of a fixed reference point may be the simplest to execute, but it does not actually address the question of the extent to which forest stocks would have been growing/declining over time in the absence of a particular bioenergy facility" (SAB Advisory, p. 29). The SAB Panel expressed concern that the reference point baseline does not address the important question of additionality, or what would have been the trajectory of biogenic CO_2 stocks and fluxes in the absence of an activity or activities using biogenic feedstocks for energy, especially in the context of forest-derived feedstocks.[6] "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. To do so requires an anticipated baseline approach" (SAB Letter, p. 2).

Through public comments to the SAB Panel during the 2011-2012 SAB peer review process, various stakeholders expressed divergent perspectives on the appropriate baseline for the draft 2011 framework report.[7] The revised 2014 framework retains the reference point baseline and adds the anticipated baseline in order to retain adaptability for potential applications, and discusses both approaches at length in the revised report and several technical appendices. However, as the SAB Panel was clear in its previous review of the reference point baseline, EPA has no outstanding technical questions for the SAB Panel on that baseline approach. This charge focuses specifically on remaining technical questions that EPA has on the future anticipated baseline approach.

Part 1 – Future anticipated baseline approach and temporal scale

It is important to consider possible treatments of time and the implications of these treatments in developing strategies for long-term and short-term emissions assessment, because the choice of

[6] The difference in net atmospheric CO_2 emissions contributions with and without changes in biogenic feedstock use is known as additionality (Murray et al., 2007). Additionality can be determined by assessing the difference in potential net atmospheric CO_2 emissions of a specific level of biogenic feedstock use over a certain period of time (in many cases the business-as-usual [BAU] baseline) versus the net atmospheric CO_2 emissions contributions that would have occurred over the same time period with a different level of biogenic feedstock use (counterfactual scenario), holding other factors and assumptions consistent between scenarios.

[7] The American Forest and Paper Association (AF&PA) supported the reference point baseline (e.g., comments submitted October 2011, March 2012) applied historically (January 2012, March 2012). The National Alliance of Forest Owners (NAFO) stated if certain feedstocks weren't categorically excluded, then the historical reference point baseline should be used (e.g., March 2012, August 2012). The U.S. Department of Agriculture stated preference for a historic baseline approach (May 2012). The Environmental Defense Fund (EDF) (January 2012, May 2012) and NCASI (October 2011, March 2012) both supported the retrospective reference point approach, though also both offered recommendations if an anticipated baseline approach was included (EDF for future anticipated and NCASI for counterfactual). Others, such as Green Power Institute (March 2012), the National Resource Defense Council (NRDC, August 2012), Becker et al. (August 2012), Biomass Energy Resource Center et al. (February 2012), and a group scientists letter to EPA (June 2014) all support some form of the anticipated baseline approach (future anticipated and/or counterfactual).

treatment may have significant impacts on the outcome of an assessment framework application. For the intended use of the revised Framework – assessing the extent to which the production, processing, and use of biogenic material at stationary sources results in a net atmospheric contribution of biogenic CO_2 emissions – there are different elements of time to consider when using a future anticipated baseline approach. These elements can include:

- Emissions horizons, assessment or policy horizons, and reporting periods (i.e., fluxes related to feedstock production may occur over many years to decades, whereas reporting may be the current year and policies may cover only a few years or decades), and
- Differences in temporal characteristics of different feedstocks (i.e., annual crops, short rotation energy crops, and longer rotation forestry systems).
- Changes in biophysical and economic conditions over time may affect or differ from those in future anticipated baseline and scenario estimates.

The SAB Panel in its previous peer review noted that "this is a complicated subject because there are many different time scales that are important for the issues associated with biogenic carbon emissions" (Advisory, page 13). They discussed multiple temporal scales associated with mixing of carbon throughout the different reservoirs on the Earth's surface at the global scale (Advisory, page 13) and climate responses to CO_2 and other greenhouse gases (Advisory, page 15), implications of temporal scales greater and shorter than 100 years, and those related to the growth cycles of different feedstock types (Advisory, page 15). The SAB Panel specifically highlighted considerations for using a 100-year or longer temporal scale for evaluating climate impacts and radiative forcing[8] as well as decay rates and carbon storage in forest ecosystems in the main text as well as in Appendices B-D. However, in its recommendations, including those for developing default biogenic assessment factors per region, the SAB Panel did not offer recommendations per what temporal scale to use in the specific context of the Framework for its intended use and scope. Instead, the SAB Panel stated that "there is no scientifically correct answer when choosing a time horizon, although the *Framework* should be clear about what time horizon it uses, and what that choice means in terms of valuing long term versus shorter term climate impacts (Advisory, page 15) and recommended that a revised framework "incorporate various time scales and consider the tradeoffs in choosing between different time scales" (Advisory, page 43).

Multiple stakeholders have also weighed in on temporal scales, some with specific recommendations on what temporal scale should/could be used for framework assessments, others with no specific recommendations but emphasizing the importance of time. In various comments submitted during the 2011-2012 SAB process, NAFO supported a 100-year timeframe (March 2012). The National Council for Air and Stream Improvement (NCASI) in October 2011 comments suggested "the need for considerable flexibility in setting the temporal scales for determining the stability of forest carbon

[8] EPA acknowledges that the long-term climate impacts of shifting from fossil fuel to biogenic energy sources is an important topic for climate change mitigation policy and also recognizes the extensive work being conducted by EPA and throughout the research community on this question. However, EPA's focus here is on a narrower, more targeted goal of developing tools to assess the extent to which there is a net atmospheric contribution of biogenic CO_2 emissions from the production, processing, and use of biogenic feedstocks at stationary sources. This more narrowly defined assessment is anticipated to be a better fit for the types of program and policy applications in which this framework may potentially be applied.

stocks. There are a range of circumstances that can cause transient trends in carbon stocks that can obscure the more relevant long-term picture."

Other groups, such as The Wilderness Society (TWS), NRDC, EDF and others, submitted comments supporting consideration of shorter temporal scales. In its comments and example calculations, TWS (in October 2011 comments) implied support for shorter temporal scales, and stated in later comments that the SAB "text appears biased toward ignoring effects that occur within a 100-year period" (May 2012). NRDC (August 2014) implied support for shorter temporal scales: "even if near-term carbon emissions increases are eventually 'made up' by regrowth over the very long term, the carbon emission from these types of biomass actually exceed those from fossil fuels for decades. This puts use of these types of biomass fuels in conflict with the urgent need for near-term carbon emissions reductions. The time profile of the carbon emission from biogenic fuel sources matters because it is critical to limit near-term global GHG emissions." This perspective was similar to that shared by Becker et al. in their August 2012 comments. EDF (January 2012) suggested a very short temporal scale (in the context of supporting a retrospective reference baseline). Others, such as the Biotechnology Industry Organization (October 2011) simply asked for "clarification on the methodology used to identify the time scale of carbon cycles."

Per the various recommendations above, the revised framework report and the technical appendices include a more detailed discussion of intertemporal tradeoffs inherent in various options for treating emissions over time in the context of assessing biogenic CO_2 emissions from stationary sources. Specifically, the revised report has: a section on key temporal scale considerations (pages 33-38); an appendix dedicated to temporal scale issues (Appendix B), which includes further discussion of temporal scales in the context of future anticipated baselines and decay rates for feedstocks that would have otherwise decayed if not used for energy, and; an appendix describing the background of and modeling considerations for constructing an anticipated baseline approach (Appendix J). Also, illustrative calculations using the future anticipated baseline estimates use future simulations and thereby explicitly incorporate temporal patterns of different feedstocks (e.g., feedstock growth rates, decay rates) into the analysis and shows how results can vary per temporal scale used (as seen in Appendices K and L). The revised framework does not recommend specific temporal scales for framework applications, but rather identifies different elements of and considerations concerning time to provide insights into the potential implications of using different temporal scales.

EPA seeks guidance on the following issues regarding appropriate temporal scales for assessing biogenic CO_2 emissions using a future anticipated baseline, using the above referenced components of the revised framework report as the starting point for the SAB Panel's discussion. As the previous 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 temporal scale both within and outside of a specific policy context.

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 CO_2 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 CO_2 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?

Appendix B: Changes in Carbon Stocks

Introduction

The following appendix describes the alternative biogenic carbon accounting formulation being proposed by the SAB. Example cases of how the formulation might be used are provided in Appendix D. The goal of this alternative formulation 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 formulation 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 feedstocks 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 stocks 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 formulation 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 stocks 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 stocks 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 carbon stock terms are based on what the stocks are and not necessarily where the stocks came from or where they are going, or the processes that might influence them. They are also the stocks that are typically inventoried and/or modeled. These stocks 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 carbon stock 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 stocks 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 increased use is the reference scenario. Note that this does not represent a comparison of stocks 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 stocks 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 stocks because the system is in a steady-state over time. This stand level "internal" comparison is irrelevant in the newly proposed formulation 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 stocks (see Appendix D for three examples).

The proposed formulation 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 formulation 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 stocks 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 stock 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 stocks and their net fluxes.

Finally, the proposed alternative formulation 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 stocks 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 stocks per area for NBE and cumulative emissions per area for PGE. The units of Δt terms would be in stocks 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 stocks 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 stocks 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:

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

where NBE_{Bt} and PGE_{Bt} represent the carbon stocks difference at time t and the cumulative potential gross emissions up to time t, respectively. The difference in carbon stocks 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:

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

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 stocks 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:

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

where TC stands for terrestrial carbon and NBE_{Bt} represents the difference in carbon stocks 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 stocks 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 stocks 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:

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

where carbon is tracked as separate live (CL), dead (CD), soil (CS), products (CP), waste stocks (CW), and transportation loss (TL) stocks.

If the BAF is solved at time T, the point at which the difference between the reference and policy scenario ceases to grow, then the equations are the same but the subscript used changes to T.

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

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

To determine T it is necessary to determine when the difference in carbon stocks 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 stocks 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 stocks between the reference scenario and the policy scenario at time t for a given system boundary B can be computed as:

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

Expanded out, assuming a time step of one year it would be: $\Delta(TC_{reference\ t} - TC_{policy\ t}) = (TC_{reference\ t} - TC_{policy\ t}) - (TC_{reference\ t-1} - TC_{policy\ t-1})$ (Eq. B-7)

which is the change in the carbon stocks 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:

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

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

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

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

Where r indicates the reference and p the policy scenarios.

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

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

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 stocks 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:

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

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 stock 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

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

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:

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

which can be rearranged as:

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

or since PGE_t can be represented by time t:

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

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

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

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

$BAF_{B\Sigma t}$ is a modification to the Biogenic Assessment 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 when emissions were contributed to the atmosphere. In some ways, we can think of this as "residence time." Initial biogenic emissions are modified over time by changes in carbon on the land. Their contribution to radiative forcing at any given point in time is a function of when those emissions took place. To take account of this time course of emissions, 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 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 feedstock 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 examples.

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 stocks 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 achieved at time T can be predicted as:

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

This simple formulation applies to all the stocks storing carbon (and the virtual stocks 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 which would consider the direct effects of harvest on the area harvested for biofuels within a region.

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

3. Atmospheric responses 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 in which the effects of substitution for fossil fuels would be considered. While this might be handled by including a substitution stock, it would be specified in the NBE and BAF terms as a change in the system boundary.

Subdividing Terrestrial Carbon Stocks

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

The inclusion of product stocks 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 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 stocks. If harvest is diverted into biofuel feedstocks, then the size of the products carbon stock 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 stock 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 stocks. By tracking the changes in this stock, the NBE equation would be more consistent.

While most of the stocks can be dealt with on a carbon dioxide basis, the waste stock (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. This would include both woody waste, depending on the manner in which it is disposed, and municipal solid waste. The stocks of these two waste stocks could be adjusted to reflect difference in stocks in terms of greenhouse gas warming. An alternative would be solve the waste carbon contribution not as a change in stocks, 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.

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 stocks 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 stocks. 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 stocks *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 C-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.

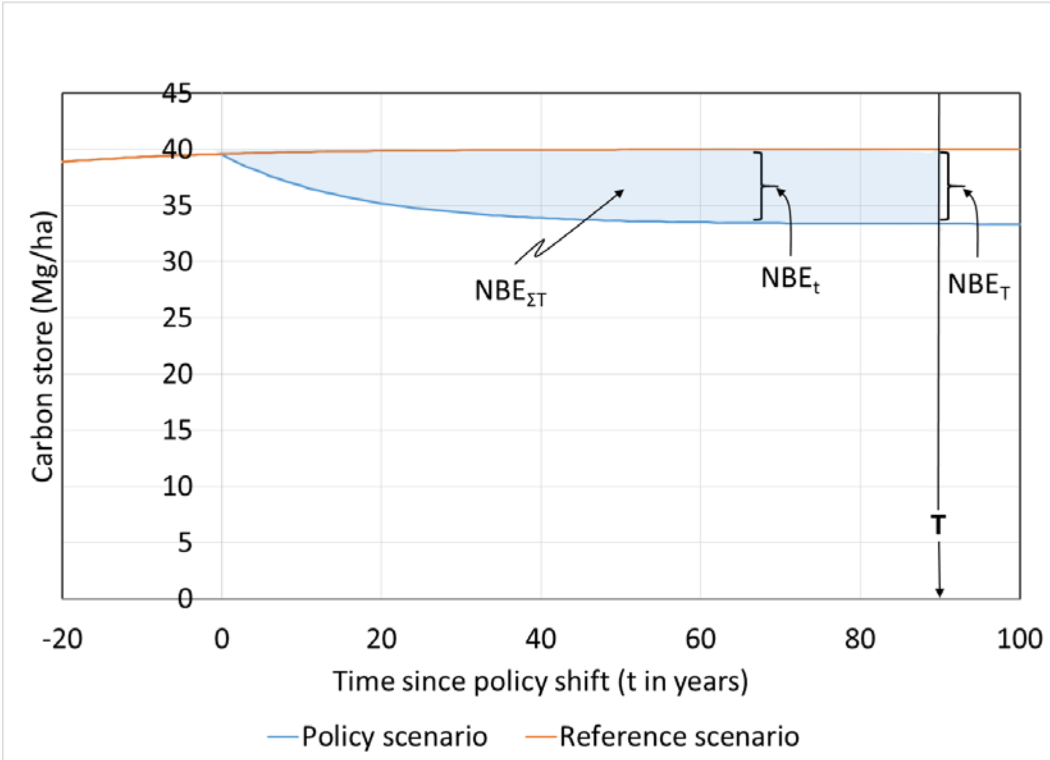

Figure C-1: A graphical illustration of the terms used in the proposed new formulation as illustrated using Case 1: Decreasing carbon described in Appendix D

In Figure C-1 the average landscape carbon stocks 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 stocks 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$_T$. The sum of all the differences up to time T (the time the differences in carbon stocks 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). For a fuller examination of Case 1 see Appendix D.

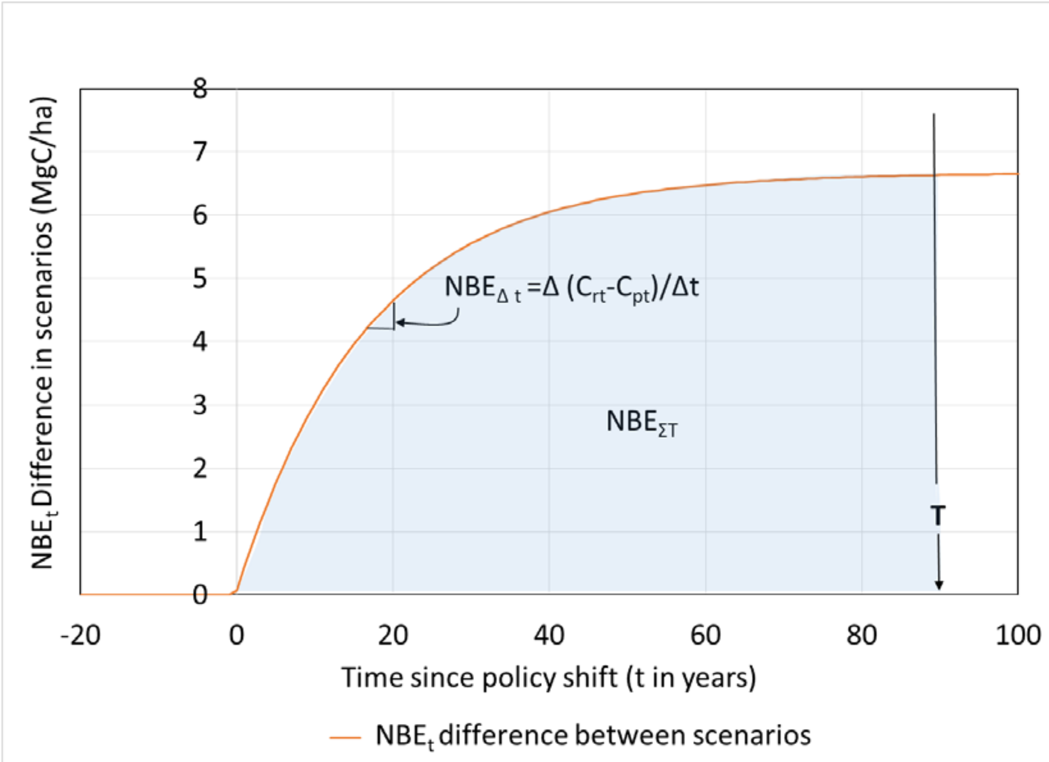

Figure C-2: The carbon stock differences (NBEt) between the policy and reference scenarios as a function of time t

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In Figure C-2 the carbon stock 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 stocks 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 stocks differences. The sum of all the differences up to time T (the time the differences in carbon stocks 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".

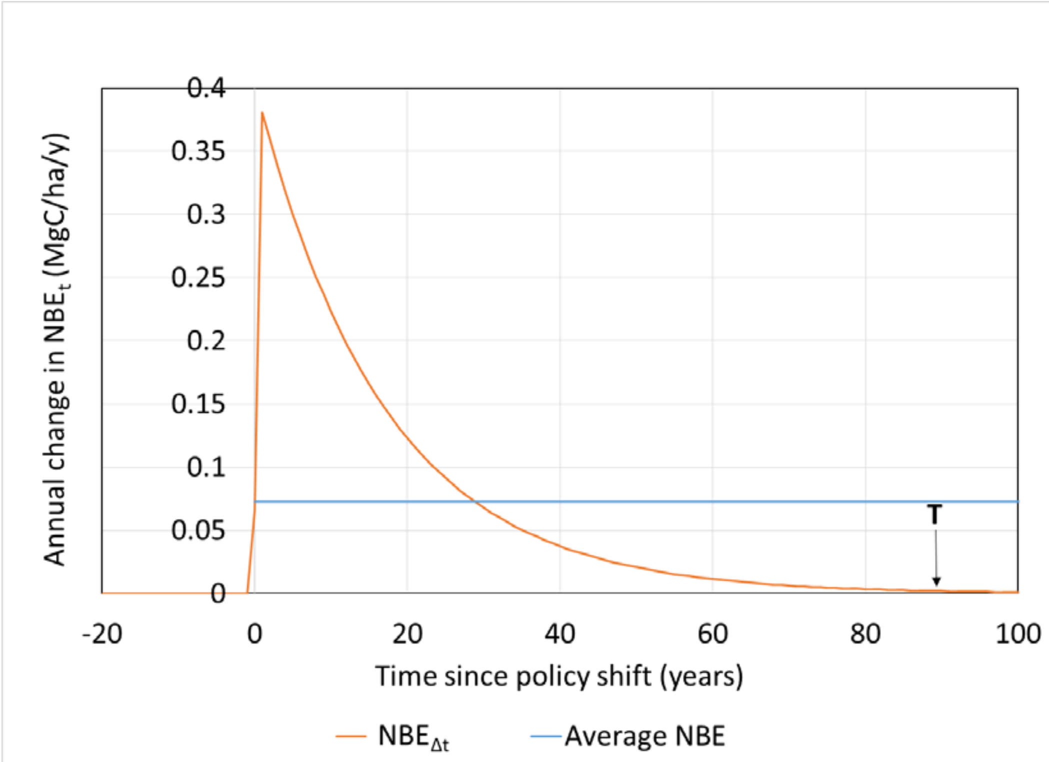

Figure C-3: The annual change in NBEt (called $NBE_{\Delta t}$ and depicted by orange line)

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 stocks 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.

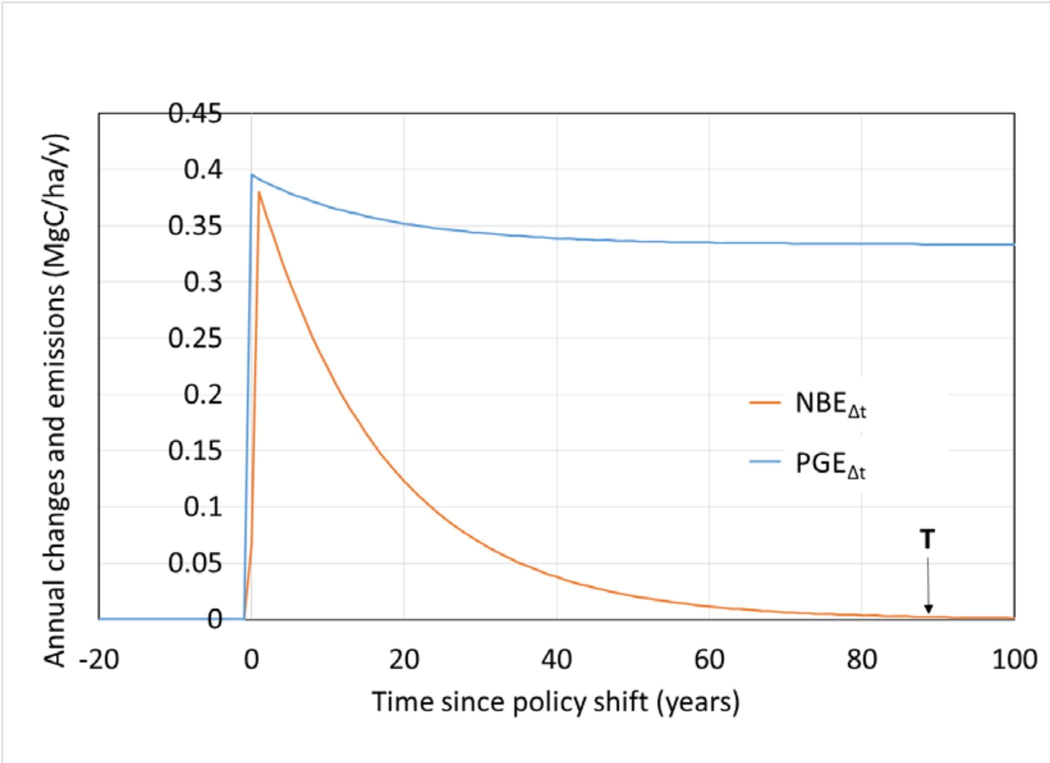

Figure C-4: BAF's calculated by dividing the Net Biogenic Emissions (NBE) by the Potential Gross Emissions (PGE) associated with burning biogenic carbon for energy.

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.

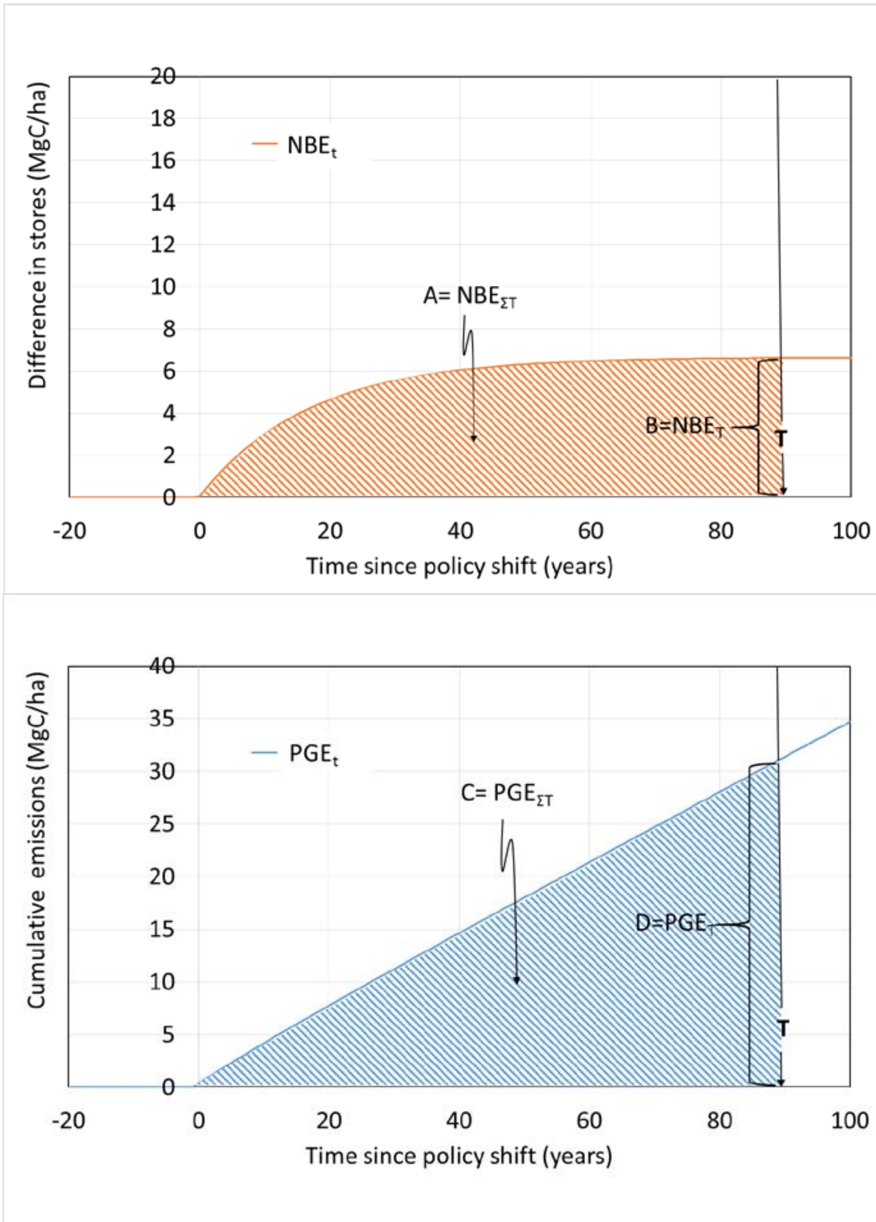

*Figure C-5: **The cumulative effects of a policy represented at a point in time (T) or over a period of time (ΣT).***

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.

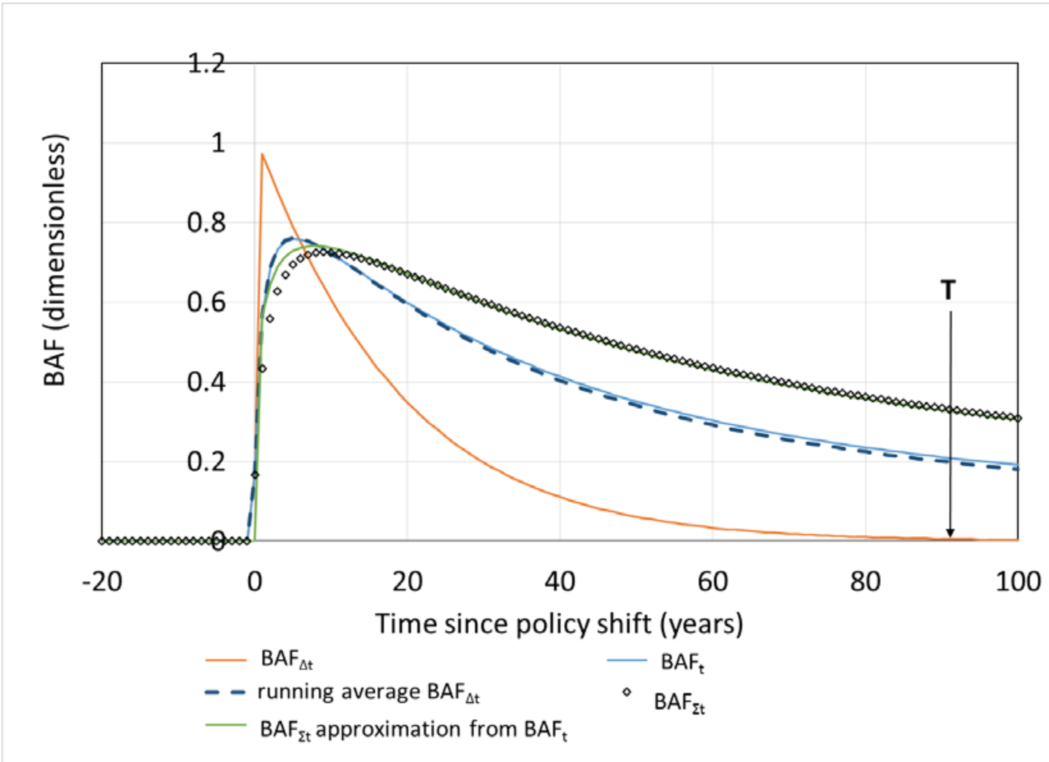

Figure C-6: The results of various ways BAFs can be calculated.

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).

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 stocks 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 stocks. 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 formulation 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 Δt is used. To indicate the time at which the effects of the biogenic harvest ceases to increase, the letter T is used. If T is used as a subscript it indicates values at time point T. To indicate the sum of the values over the interval T, the subscript ΣT is used. If the sum over an interval over t years is used, the subscript Σt is used to indicate that sums at various time intervals are being used. It is acknowledged that it would be simpler to not indicate which specific time concept is used; however not specifying the differences leads to confounding related concepts that need to be kept separate.

The following cases were generated using a simple input-output model programmed in Stella with one stock that represented the average stocks 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 feedstock. 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 formulation 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 stock 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 stocks of carbon in two cases: a reference case to represent “business as usual” conditions without policy-induced feedstock harvesting and a policy case to represent policy-induced increases in 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 stocks 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 feedstock. 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 stock 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.

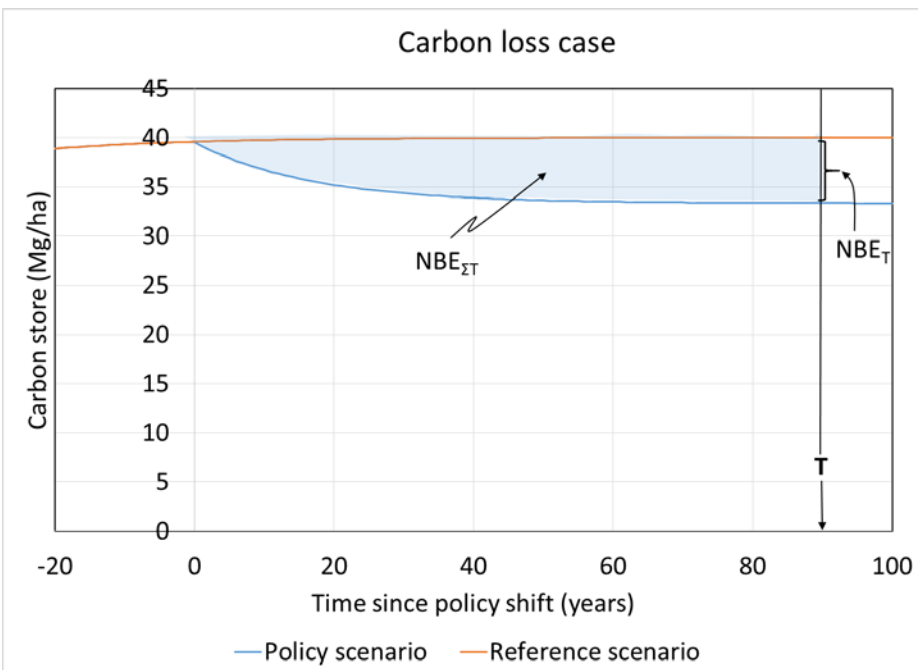

Figure D-1: Carbon Loss Case

Figure D-1. shows that the landscape level average carbon stocks when harvest for biofuels (the policy scenario) leads to a decreases in stocks 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 stock 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 stock is harvested and this harvest reduces the stock to be harvested, then absolute amount harvested must decline somewhat as a new age structure is imposed on the landscape.

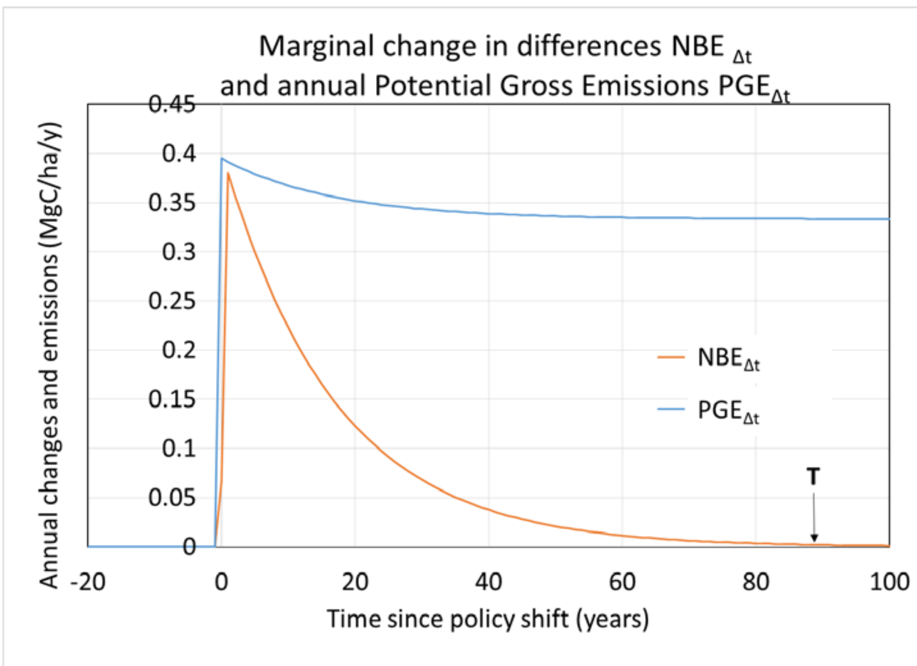

Figure D-2: Rate at which differences between reference and policy scenarios is growing ($NBE_{\Delta t}$) and annual potential gross emissions $PGE_{\Delta t}$).

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 stocks 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.

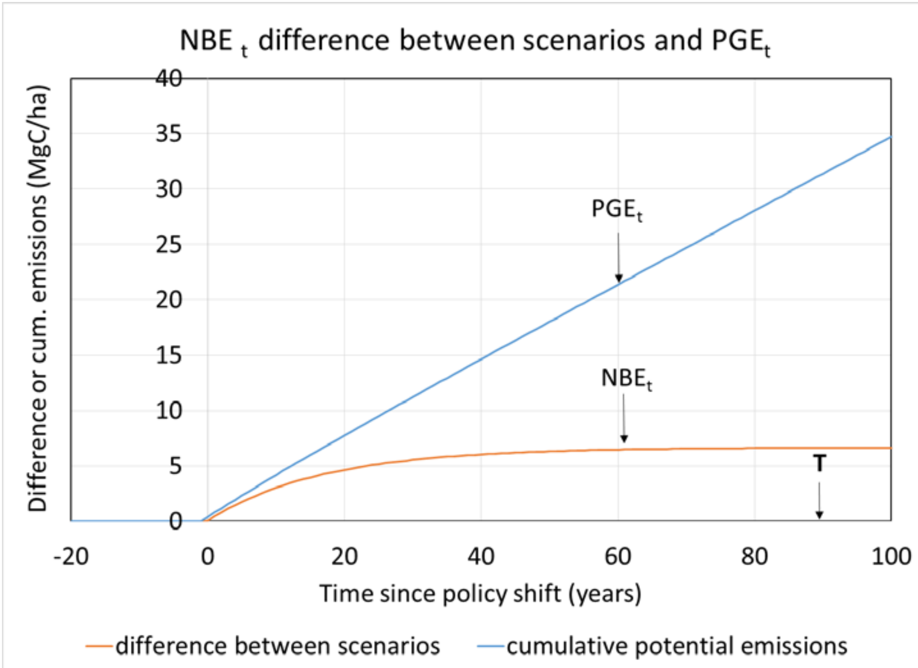

Figure D-3: ***Time course of the difference between scenarios (NBE_t) and cumulative potential gross emissions (PGE_t).***

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 stocks 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 stocks 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 time path of biogenic carbon emissions in which initial emissions are modified over time by changes in carbon on the land. 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.

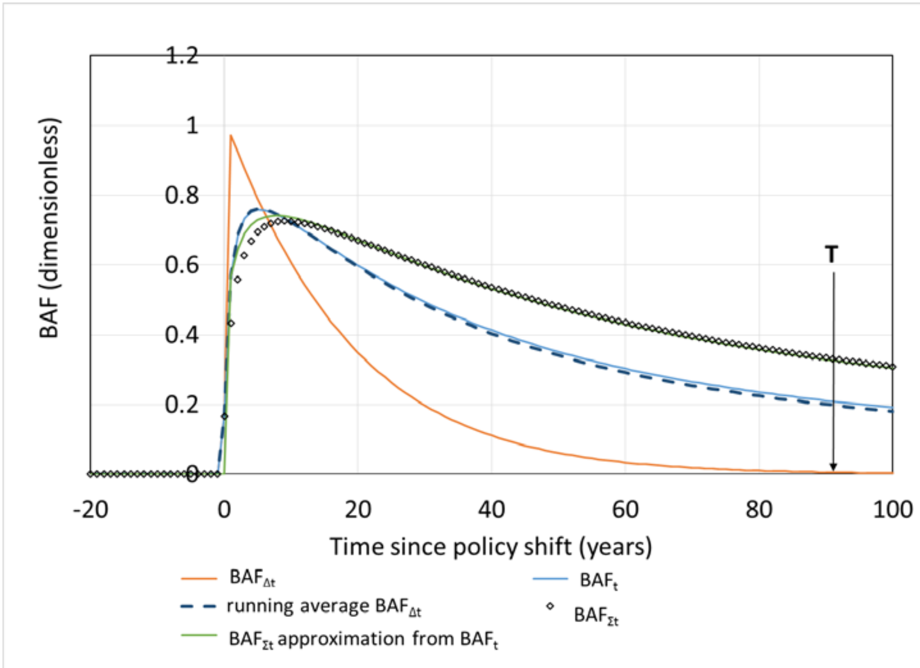

Figure D-4: Comparison of BAF calculation methods for the case in which biofuel harvest reduces carbon stocks relative to the reference scenario.

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 stocks in the policy case are 24.9% higher than that for the reference case (Figure D-5).

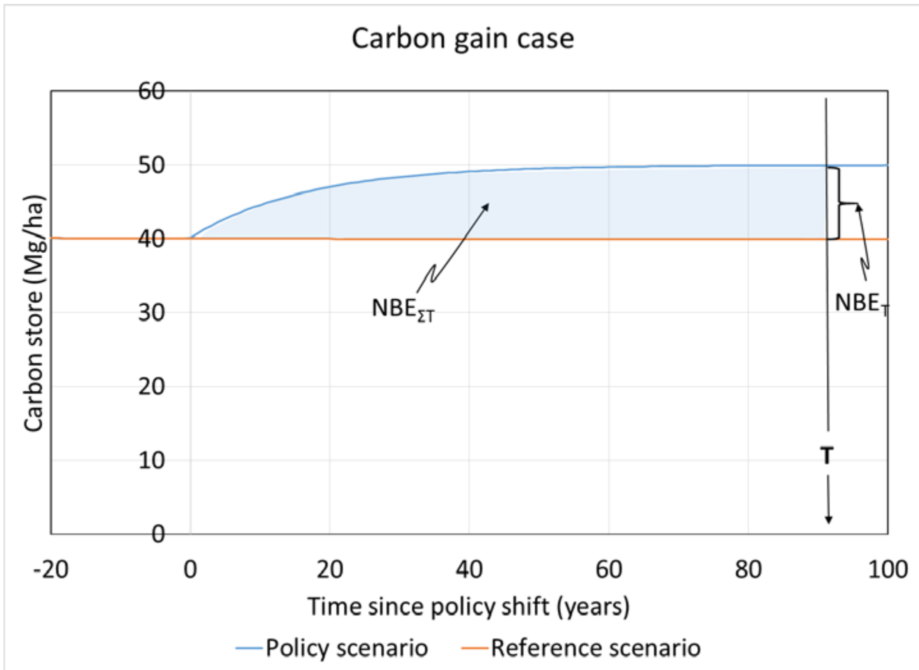

Figure D-5: Carbon gain case

Figure D-5 shows the landscape level average carbon stocks for the case when harvest for biofuels (the policy scenario) leads to a increases in stocks 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.

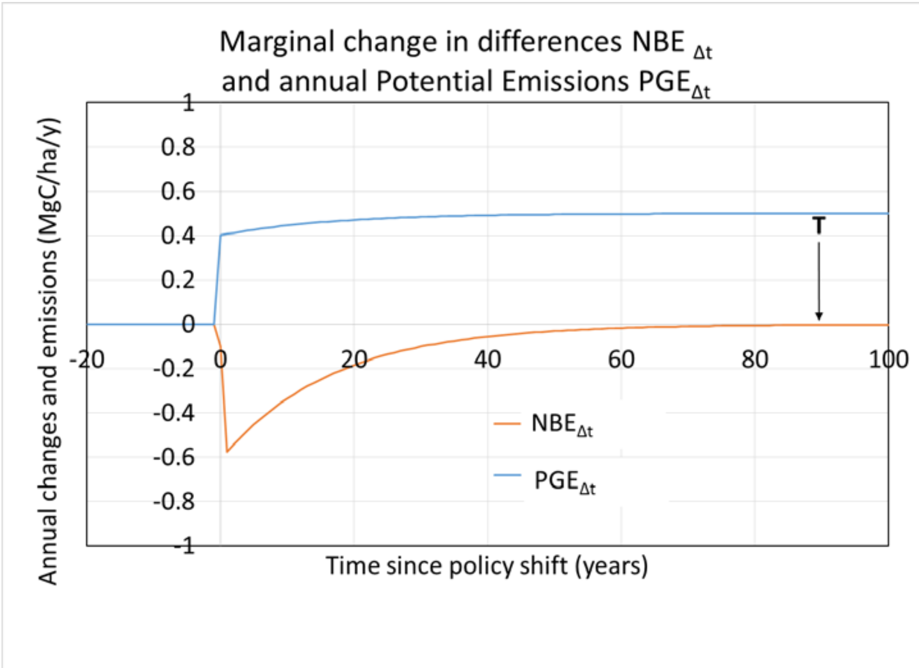

Figure D-6: The rate at which the difference between the reference and policy scenarios is growing (NBEΔt) and the potential gross emissions from biofuel use each year when there is a gain of carbon caused by the policy scenario.

While the differences in scenario stocks (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.

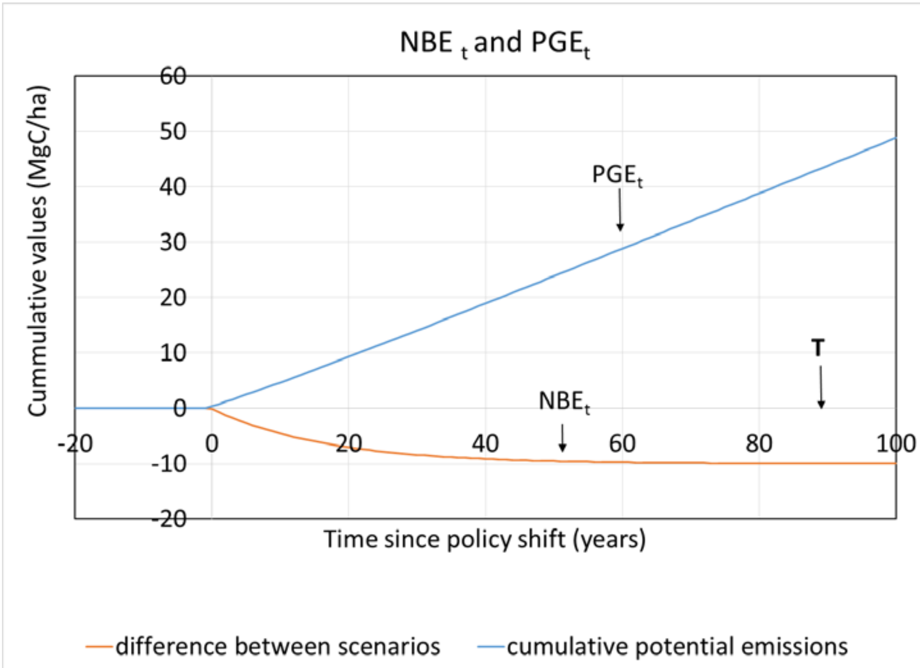

Figure D-7: The time course of the difference between scenarios (NBEt) and cumulative potential gross emissions (PGEt) when there is a gain of carbon caused by the policy scenario.

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 stocks 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.

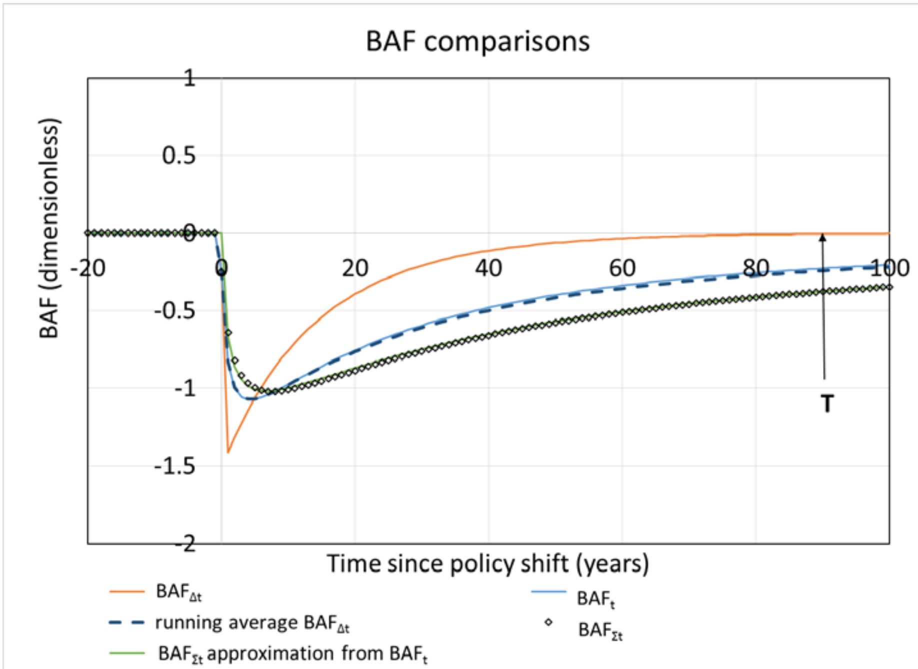

Figure D-8: Comparison of BAF calculation methods for the case in which biofuel harvest increases carbon stocks relative to the reference scenario.

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.

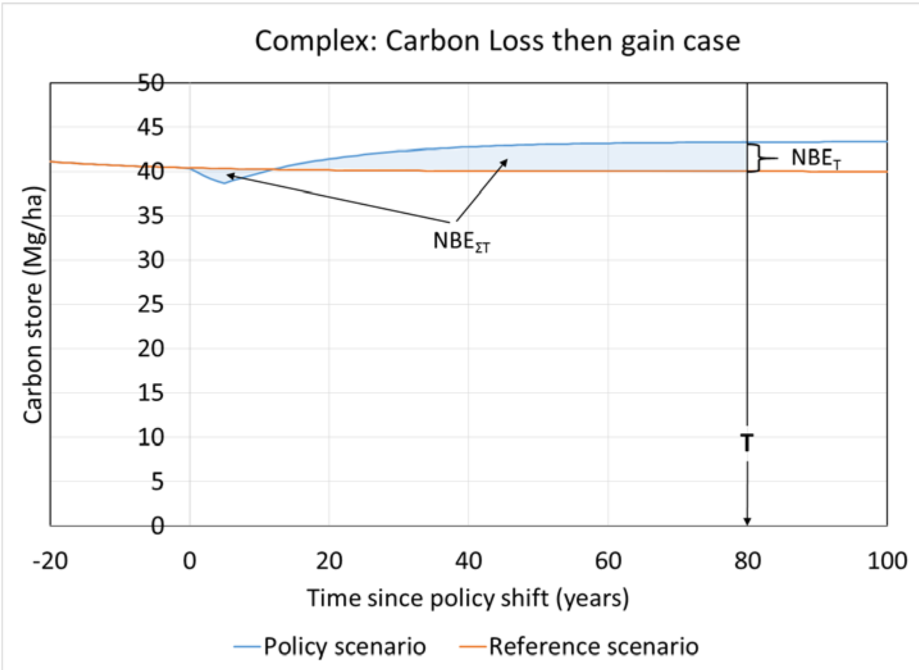

Figure D-9: Carbon loss then gain case

Figure D-9 shows the landscape level average carbon stocks for the case in which harvest for biofuels (the policy scenario) leads to an initial decrease, but an eventual increase in carbon stocks 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.

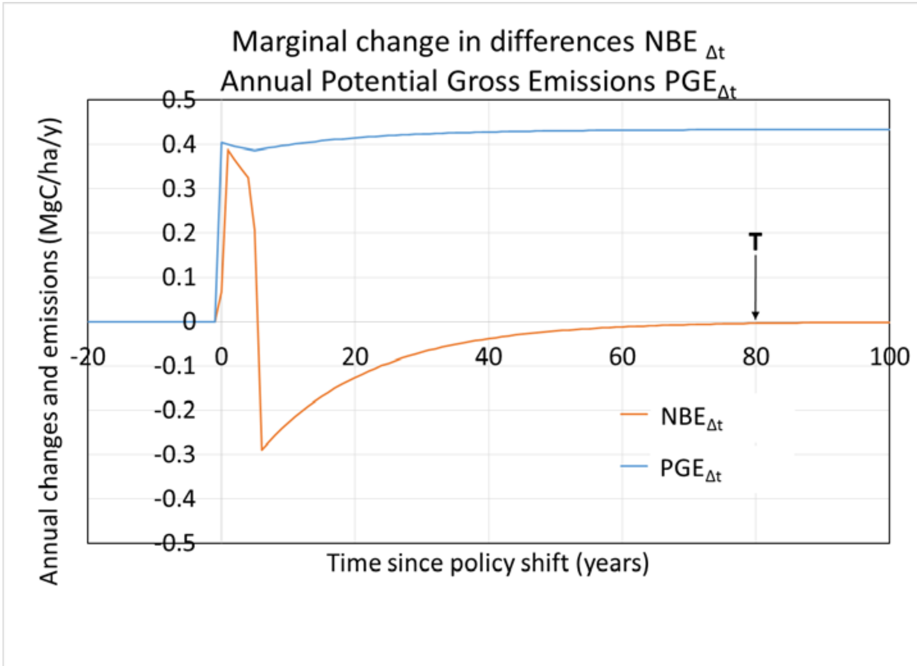

Figure D-10: The rate at which the difference between the reference and policy scenarios is growing (NBEΔt) and the potential gross emissions from biofuel use each year when there is a loss then a gain of carbon caused by the policy scenario.

While the differences in scenario stocks (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.

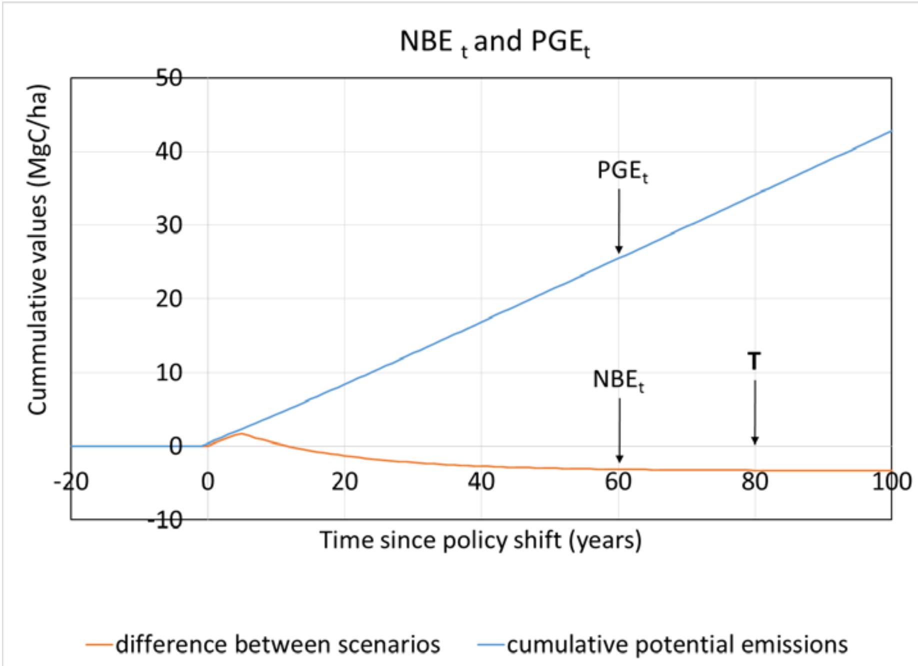

Figure D-11: The time course of the difference between scenarios (NBEt) and cumulative potential gross emissions (PGEt) when there is a loss then gain of carbon caused by the policy scenario.

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 stocks 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.

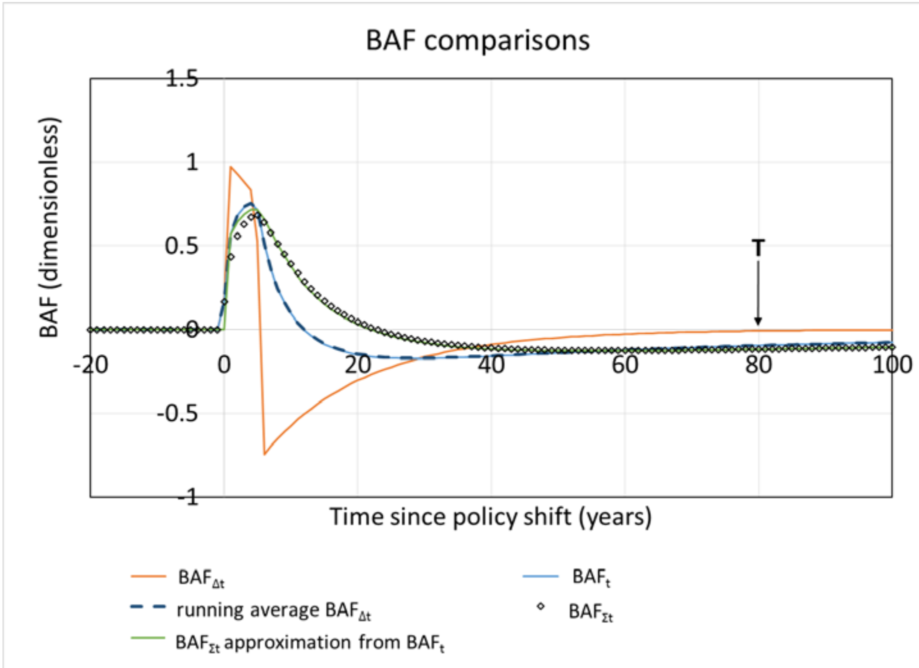

Figure D-12: Comparison of BAF calculation methods for the case in which biofuel harvest decreases and then increases carbon stocks relative to the reference scenario.

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 stocks develops between the reference and policy scenarios; however, the carbon stocks 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.

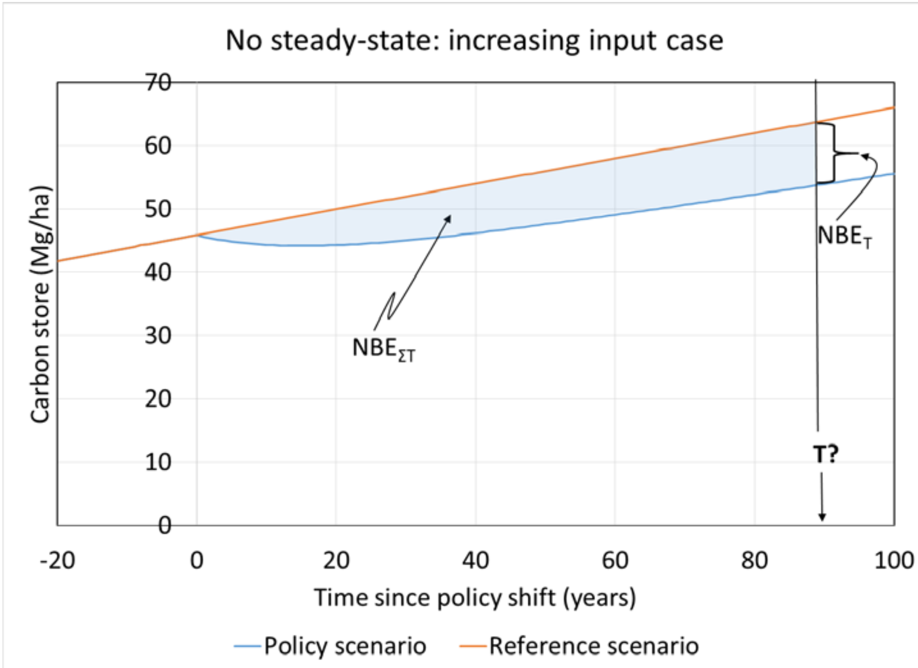

Figure D-13:The landscape level average carbon stocks for the case in which harvest for biofuels (the policy scenario) leads to a decrease in carbon stocks compared to the reference scenario, but both scenarios have increasing carbon stocks relative to time 0.

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

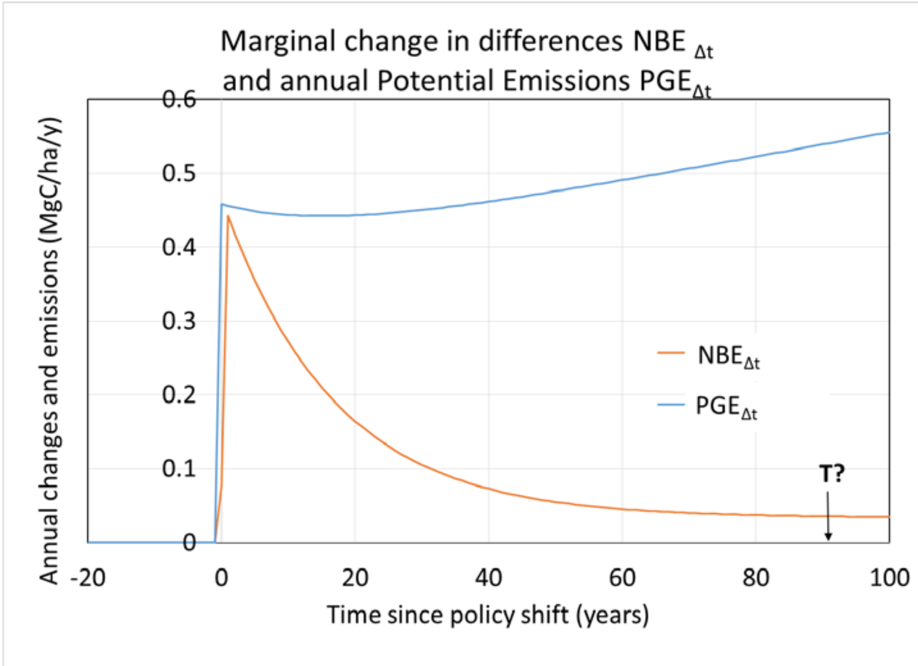

Figure D-14: The rate at which the difference between the reference and policy scenarios is growing (NBEΔt) and the potential gross emissions from biofuel use each year when both the reference and the policy scenario have an increase in input related to an environmental change.

When the differences in scenario stocks 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.

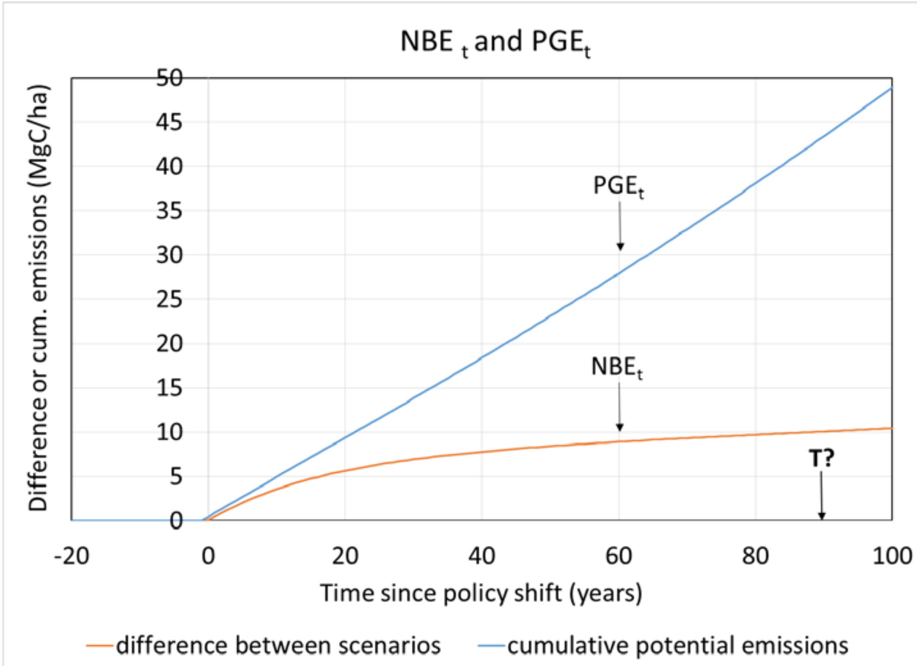

Figure D-15: The time course of the difference between scenarios (NBEt) and cumulative potential gross emissions (PGEt) when both the reference and the policy scenario have an increase in input related to an environmental change.

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.

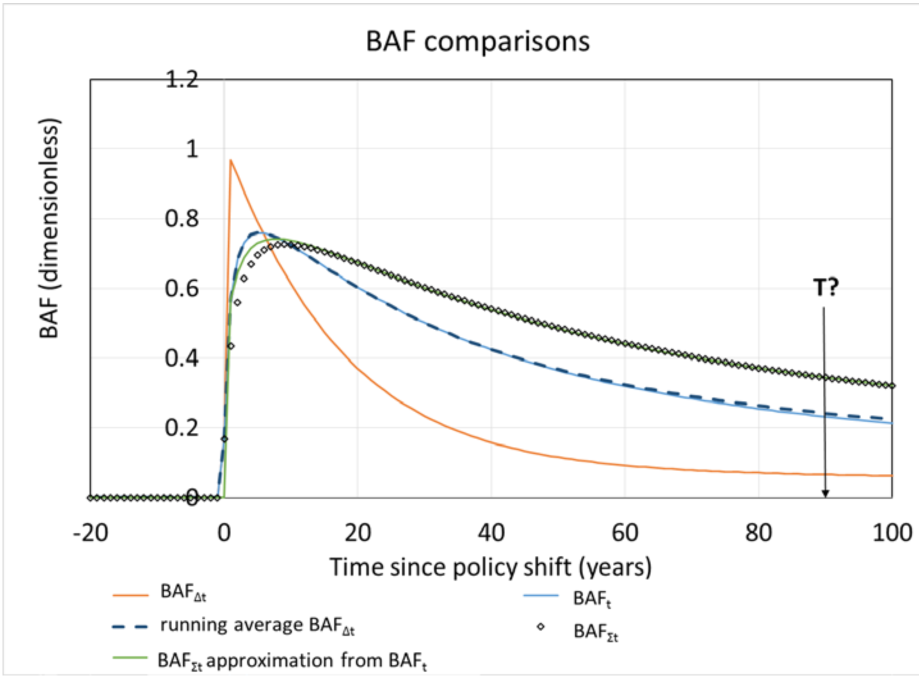

Figure D-16: Comparison of BAF calculation methods for the case when both the reference and the policy scenario have an increase in input related to an environmental change.

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 stocks develops between the reference and policy scenarios; however, the carbon stocks 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.

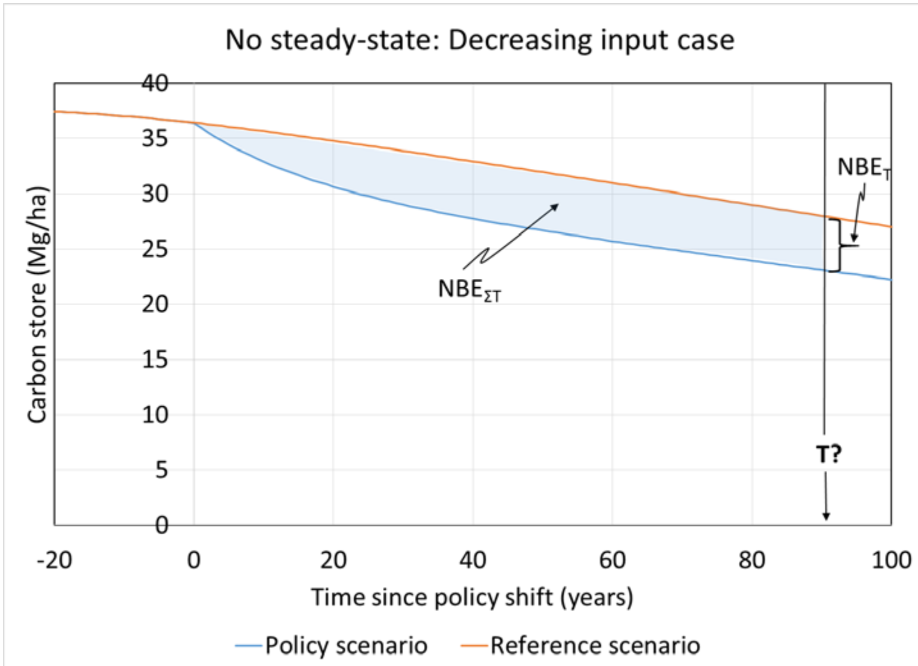

Figure D-17: The landscape level average carbon stocks for the case when increased harvest for biofuels (the policy scenario) leads to a decrease in carbon stocks compared to the reference scenario, but both scenarios have decreasing carbon stocks relative to time 0 caused by an environmentally driven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

Figure D-17 shows the landscape level average carbon stocks for the case when increased harvest for biofuels (the policy scenario) leads to a decrease in carbon stocks compared to the reference scenario, but both scenarios have decreasing carbon stocks 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.

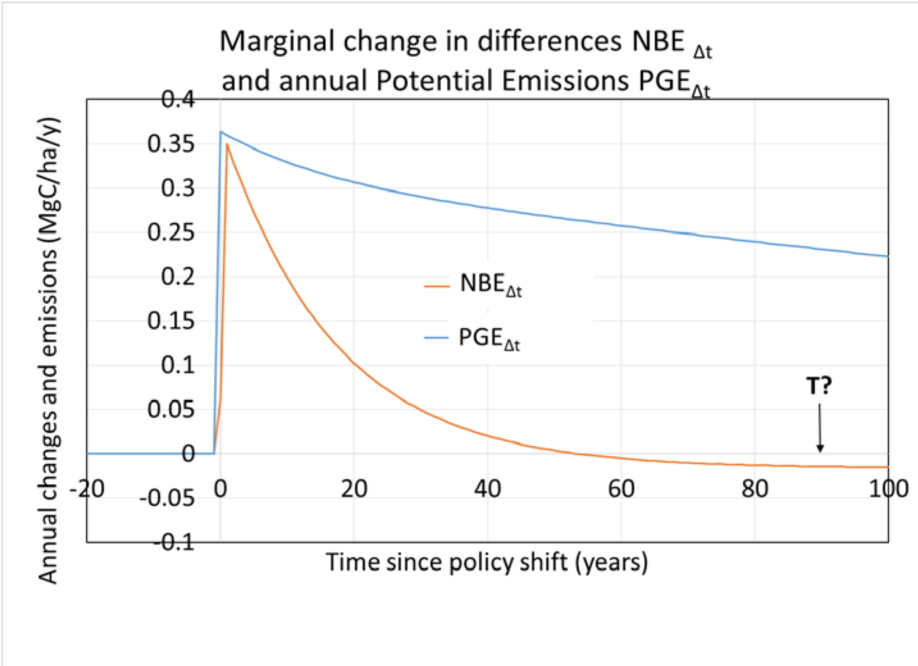

Figure D-18: The rate at which the difference between the reference and policy scenarios is growing (NBEΔt) and the potential gross emissions from biofuel use each year when both the reference and the policy scenario have a decrease in input related to an environmental change.

When the differences in scenario stocks 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.

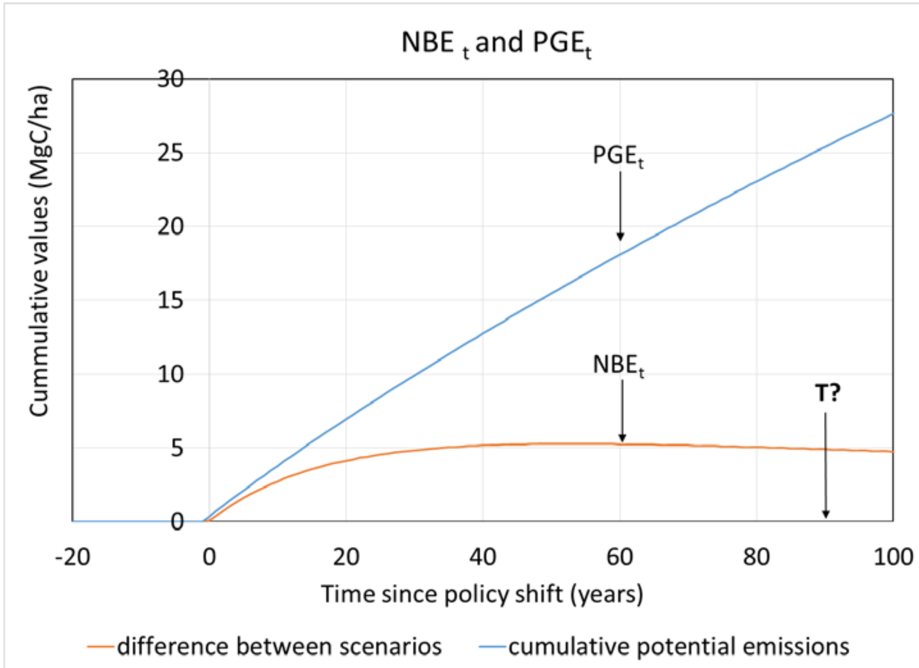

Figure D-19. The time course of the difference between scenarios (NBEt) and cumulative potential gross emissions (PGEt) when both the reference and the policy scenario have a decrease in landscape input related to an environmental change

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.

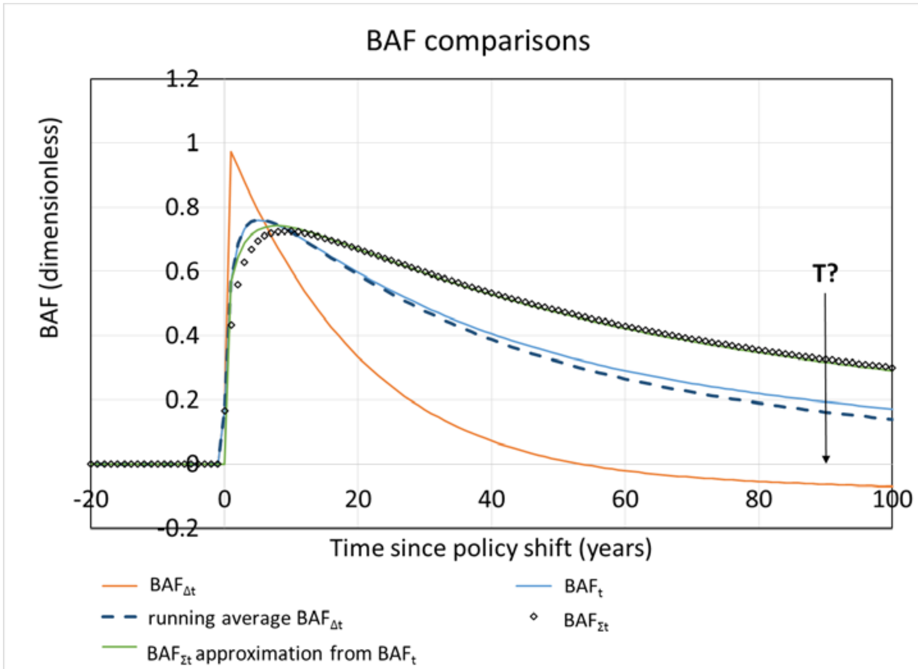

Figure D-20: Comparison of BAF calculation methods for the case when both the reference and the policy scenario have a decrease in input related to an environmental change.

Summary of Cases Regarding BAF

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

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

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

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