From:	Harmon, Mark
To:	Carpenter, Thomas
Subject:	additional comments
Date:	Wednesday, September 26, 2018 7:22:04 PM
Attachments:	Additional comments by Dr Harmon.pdf Reconcilling systems with different time dynamics.pdf

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Dear Thomas:

There was a request for any additional comments. See the attached files. One is a draft appendix that was not included in the panel's report. I think this was a major mistake because its exclusion give the impression there is one scientifically determined T. There is not. The other file has my short comments on this an on some other issues.

As a general observation it is not clear that the authors of the current report examined the appendices. That is where a lot of the details of the previous work were given. By doing so they have given a very misleading impression that many of the questions they are dealing with now were not addressed. They were.

thanks,

Mark

Additional comments by Dr. Mark E. Harmon

I am adding some additional comments in reaction to some of the issues covered in today review of the Biogenic Carbon report.

The first is to note that it is perfectly true that if the time horizon is based on policies, then if there are different policy horizons will have to be reconciled. However, it is not correct to imply that if the time horizon is determined by using T, a scientifically/mathematics that one will not have the same problem and that policy decisions would not be involved. I am attaching a report which was excluded from the panel's report that makes it clear that if the T's for various ecosystems supplying biogenic carbon differ, then one has to reconcile these differences. There are a number of ways to do this and it is not clear that science per se can tell one which one to use. And since they all yield different results there would be consequences to deciding to use one possible approach versus another.

I still find that all the conversations are based on the premise that climatic effects are the only effects that involve carbon dioxide. I am not sure why there is such a blind spot regarding ocean acidification, but its consequences will prove quite serious. And the time response of ocean acidification is very different from that of climate. So even if one is using the response time of the system to set the time horizon this does not solve the problem of how different response times would be resolved.

Finally, I heard some discontent that the sensitivity of the various BAF's to different scenarios was not explored. From the current report one would certainly get that impression. However, it is simply not the case. I know because I conducted them and wrote the appendix that they were presented. This is why it is important for the revised report to refer to specific parts of the previous panel's work. I am sure that lots more work remains, but it is not helpful or productive to not refer to the existing work.

Integrating Systems with Different Time Horizons

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Introduction

This report describes the basic science behind the speed of system responses to the policy scenario and examines how systems with different response times could be integrated. It differs in that the focus is on multiple systems as opposed to one system at a time found in Appendices C-E. The basic problem is that while determining the time horizon for one system is straightforward, it is more complicated to reconcile multiple systems. There are multiple ways to do this integration that lead to different solutions. The objective here is to examine how each might work and how they might differ.

Basic Science of System Response Time

In terms of the BAF, the time horizon of response of a system, T, is defined as the time for a large majority of the difference between the reference and policy scenarios to be expressed. In theory T is reached when this difference ceases to grow and when the $NBE_{\Delta t}$ reaches zero. However, in practice T needs to be defined as the point at which either a very large share of the difference has been expressed (e.g., 99%) or alternatively when $NBE_{\Delta t}$ reaches a minimal level near zero. This is because the response typically follows a negative exponential or natural growth function (see Appendix C and D) that may have very long "tails" representing trivial loss or accumulation (recall that a negative exponential function can approach zero, but never actually equals zero). For these types of responses the convention is to use a proportion of the mass or absolute rate of change to determine the timing of the system.

Several factors determine when the difference in carbon stores between the reference and the policy scenario stabilizes, an indication T has been reached (Appendices B, C, D). The first major factor is the average time carbon stays in the part of the system responding. Specifically, the longer carbon stays in a system part, the slower the response time to a policy scenario. Another major factor influencing system response (i.e., T) is the rate and at which the policy is implemented. Specifically, the slower a policy is implemented, the longer the system response time. To a large degree policy implementation is dependent on the harvest interval with annual cropping systems being implemented faster than long-term ones. However, implementation also depends on whether the policy involves a one-time change versus a series of changes over time, with the latter slowing system response more than the former. In addition, system response time is also determined by underlying changes in the environment, particularly if those changes interact more with the policy scenario than the reference scenario (see Cases 4 and 5 in Appendix D).

Olson (1963) derived the mathematical relationship to predict when an ecosystem store reaches a steady-state. We can borrow from this derivation to predict when NBE_t reaches a constant level, that is T. If the difference between the reference and policy scenarios follows a natural growth function we can define T as the time for X% of the difference to be expressed. Typically X%

would be defined as 95% or 99% by convention to represent a large share of the change. The natural growth function to predict NBE_t is:

$NBE_t = NBE_{maximum} (1-\exp(-k\ t))$

We can rearrange this formula so that NBE_t is expressed as a proportion of the value at time t:

$NBE_t / NBE_{maximum} = 1-\exp(-k\ t)$

Since the timing of the natural growth function and a negative exponential equation are similar (they are complements) one can use the latter as it is easier to solve:

$NBE_t / NBE_{maximum} = \exp(-k\ t)$

Taking the natural logarithm of both sides of the equation allows one to solve for k, the relative rate the difference increases per unit of time:

$t = -\mathrm{Ln}\ (NBE_t / NBE_{maximum}) / k$

If 95% and 99% of being reached is used then, respectively:

$T_{0.95} = -3/k$ and

$T_{0.95} = -4.6/k$

Response Time Qualitative Examples

We can test this relationship by qualitatively examining several general cases. If the feedstock is the part of the system responding, then the speed is largely controlled by the interval of harvest, which is why annual crop systems respond more quickly than perennial ones and why long rotation systems respond more slowly than short rotation ones. However, other parts of the system can respond that are slower or faster than the growing stock and the overall system speed depends on the magnitude of this response relative to that of the growing stock. This means that an annual cropping system can have a slow response if the mineral soil carbon is the main pool responding and a rapid one if the growing stock is the main response pool. It also means that long-rotation systems can respond more quickly than the growing stock if pools with faster dynamics (e.g., slash disposed by prescribed burning) dominate the response. An analogous relationship exists when multiple feedstocks are considered at the regional level: the time T is reached depends on the speed of the feedstock systems and their relative abundance. Specifically, the more abundant a feedstock system, the more it should dominate a region's carbon response time. Additionally, the more divergent the speed of the feedstock systems, the more the slower system is likely to dominate the region's overall timing.

Possible Integration Methods

Based on these factors determining the T for a given feedstock in a region would not only dependent, as often expressed, on the harvest interval, but also the speed of the parts responding and the rate of policy implementation. When these differ within a region, then one possible approach to reconcile the different response time is to use the dynamics of the slower system as a comparator to standardize the other responses. Another approach would be to use the overall

response of all the dominant variations of a feedstock system weighted by their abundance to determine the overall feedstock T. Similar approaches could be used to integrate feedstocks within regions or to integrate regions: one could select the comparator T based on the slowest response or one could consider the integrated system to determine the overall T. While either system could be used the latter involves a natural integration as one moves upward from individual pools to the ecosystem to the region to the "globe". That is because the dynamics of the dominate pools responding at the ecosystem level determine the overall dynamics of different feedstocks and the dominate feedstocks in regions determine the dynamics of regions. This can logically be extended inter-regionally with the dominant feedstocks in the different regions controlling the overall speed of the global response.

Exploratory Example of System Integration

In many regions a number of biogenic fuel stocks will be used, some with very rapid abilities to respond and other with very slow abilities. This raises the question of how feed stocks with very different temporal dynamics would be integrated. I explored this process using a set of theoretical systems with different values of T (Figure F-1) that ranged from 2.5 to 320 years. For each of these systems the time that $NBE_{\Delta t}$ approached zero is indicated. To make the systems comparable $NBE_{\Delta t}$ was rescaled to make the maximum value the same for all the systems.

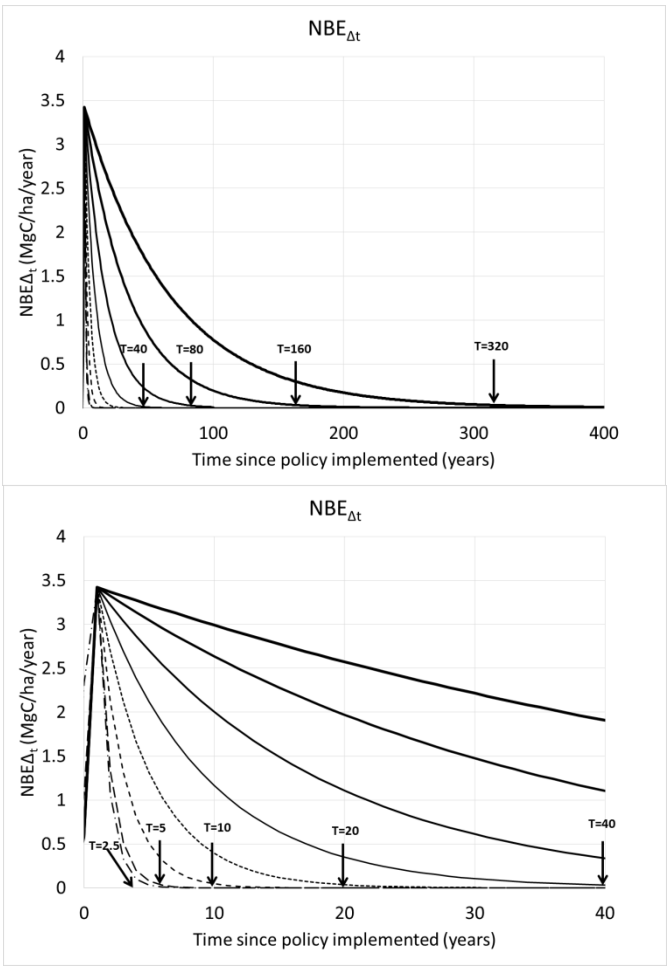

Figure F-1. Illustration of how the rate at which NBE_t is changing as a function of time since policy implementation (lower panel shows detail of faster systems).

In Figures F-2 and F-3 systems with different abilities to respond, as indicated by T, are compared for BAF_t and $BAF_{\Sigma t}$. The approximate point at which T is reached for each system is indicated by a numbered circle corresponding to the value of T. For both cumulative BAF's the value rises to a peak and then falls off with time. The faster the system is to respond, the lower the peak BAF is, the earlier it appears, and the faster it approaches zero as the time since the policy was implemented increases. This analysis indicates that while the peak BAF is reduced for rapidly responding ecosystems, it does not go to zero unless the ecosystem can instantly recycle the carbon released by biogenic fuel combustion.

To integrate these different dynamics a common timeframe needs to be selected. One method would be to select a time guided by a specific policy. However, this is problematical because it is not based on carbon dynamics and it could distort the temporal signals given by the different systems. If for example, the system with a T of 80 years was selected as the comparator because it is intermediate in terms of dynamics (see the vertical dashed line), then those with a T of 160 and 320 years would have a BAF_t 1.8 and 2.7 times higher than the comparator system. In contrast, the system with a T of 40 years would have a BAF_t 0.52 times lower, that of the system with a T of 2.5 years would essentially be zero. Selecting a time of assessment that is very short can create problems if the BAF's for the slowest systems have not peaked. For example, if a T of 5 years is selected, then BAF_t of the slowest system (T =320 years) would be 4% lower than its peak value. Since $BAF_{\Sigma t}$ is slower to respond than BAF_t it is more sensitive to the "fast" comparator effect than BAF_t. Selecting the slowest system as the comparator would have the benefit of at least including all the other systems' carbon responses. Although the BAF's of the other systems would be lower than if a faster system was used as the comparator, this choice would not lead to all systems having a cumulative BAF of zero. That would be true for the fastest systems, but even those 2 to 4 times faster than the slowest system would have a BAF above zero. Since $BAF_{\Sigma t}$ is slower to respond than BAF_t it is less sensitive to the "slow" comparator effect than BAF_t.

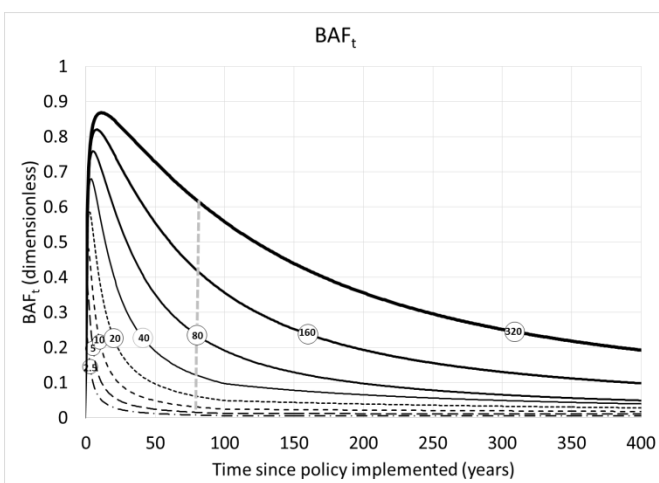

Figure F-2. Response of BAF_t for systems with different values of T.

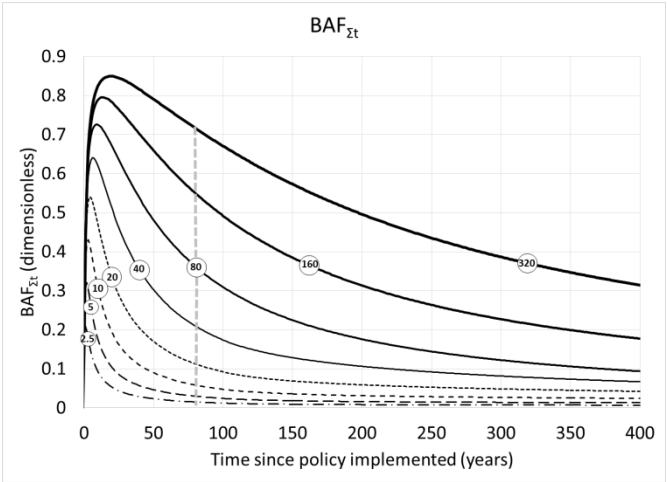

Figure F-3. Response of $BAF_{\Sigma t}$ for systems with different values of T.

Another possibility to compare systems would be to use the cumulative BAF at each system's T. Plotting the value of BAF at time T for all the systems reveals the problem with this approach (Figure F-4): the values of cumulative BAFs and the peak value of $BAF_{\Delta t}$ are similar over a very large range of T (i.e, 20-320 years). This method would effectively ignore the different temporal dynamics of systems; however, it would distinguish very fast systems (T<10 years) from the rest.

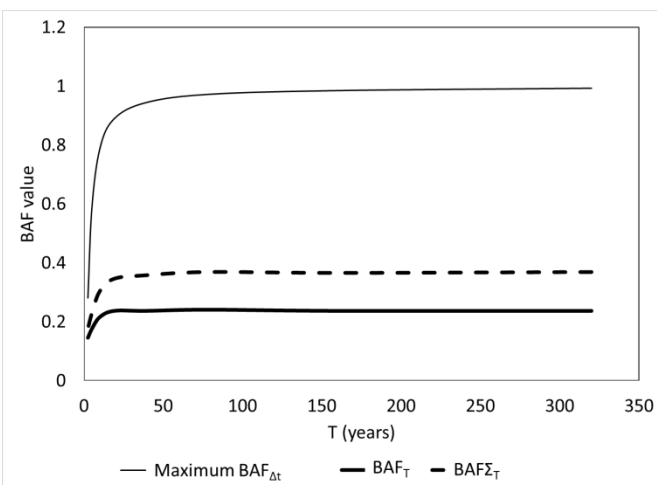

Figure F-4. BAF of different systems as a function of T, the time horizon.

Each of the systems of integration described above is somewhat artificial, although as noted using the system with the slowest response time does at least assure that all the carbon effects are completed. However, even that system is a bit artificial because it does not address the abundance of subsystems. Functionally it would make more sense to not only include the timing, but also the relative contribution of the different systems. This would take advantage of

the natural integration that occurs as one moves from pools to feedstocks to regions and even among regions. The basic rule would be to analyze the integrated system and to use the dynamics of the overall system to define an overall T.

An example of this integrated approach is illustrated in Figure F-5. In this example two systems with very different dynamics were combined in different combinations ranging from 100% of the fastest (T=5 years) to 100% of the slowest system (T=160 years). The various combinations ranged between these two endpoint systems. The presence of the slow system leads to a long "tail" in the overall system, which lends some support to selecting the slowest system as the comparator. However, when T is selected based on either the amount of the maximum NBE_t achieved (in this case 99%) or a very small fraction of the peak $NBE_{\Delta t}$ (in this case 1%), the overall T of the combined system is a function of the mixture (Figure F-6). As a reference, I also examined a very simple method in which the two end member values of T were mixed by abundance. This indicates that while the integrated method responds to the mixture, it is more conservative than the simple mixture model of T. The integrated method based on a minimum fraction of $NBE_{\Delta}t$ is more responsive than that based on the fraction of maximum NBE_t achieved. It should be noted that the fraction of maximum NBE_t achieved when $NBE_{\Delta}t$ is 1% of the maximum value is not necessarily 99%. However, in this example the percent of the maximum NBE_t achieved was above 97% for mixtures in which there was at least 25% of the slow system. When the fraction of the slow system dropped to 5% slow, the flux-based T was reached when 90% of the total NBE_t was reached. While we do not have a recommendation as to which criteria to use to select T, we do note that it would influence the value of the overall T and the amount of carbon effect considered.

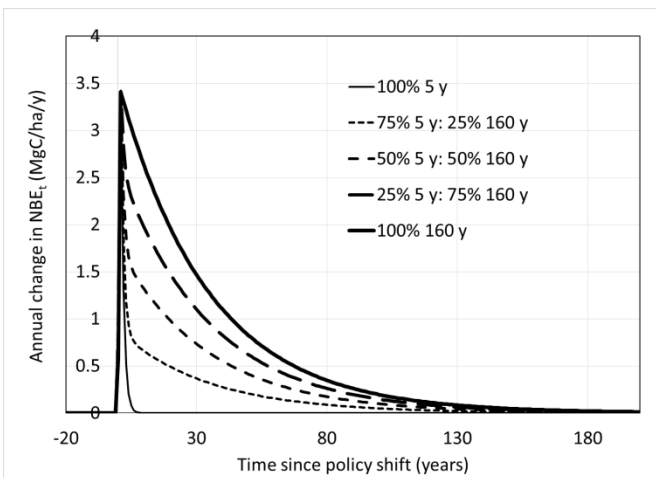

Figure F-5. Annual change in NBE_t (i.e., $NBE_{\Delta t}$) as function of time since policy shift and system mixtures.

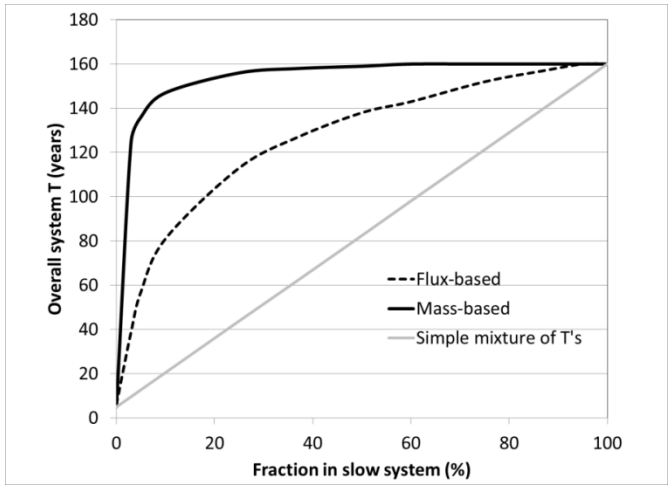

Figure F-6. Overall T for integrated systems as a function of system mixture.

The final step in estimating the cumulative BAF of each of the component systems would be to evaluate the cumulative BAF of each of the systems using the overall T. This is illustrated in Figure F-7 for a system in which the overall T is selected based on 1% of the maximum $NBE_{\Delta t}$ value. Both cumulative BAF's are most responsive when the slow system falls below 25% of the overall mixture. Moreover the slower systems are more responsive than the faster ones when the slow system is more than 25% of the mixture. This integrated system can be compared to that in which the slowest system is the comparator by using the value when the slow system is 100% of the mixture. For systems with T's less than 20 years, the cumulative BAF is not that different using the either integrated or the slowest system as comparator method. For systems with T's greater than 80 years, the two systems differ substantially. Although the method using a fraction of the mass difference is not illustrated, it is more conservative than the flux-based method and would likely be less responsive than the flux-based method. This would mean that the integrated and slowest system as a comparator method would be more comparable. EPA would need to make a policy decision of which method of selecting the overall T given that each method provides different estimates of cumulative BAF.

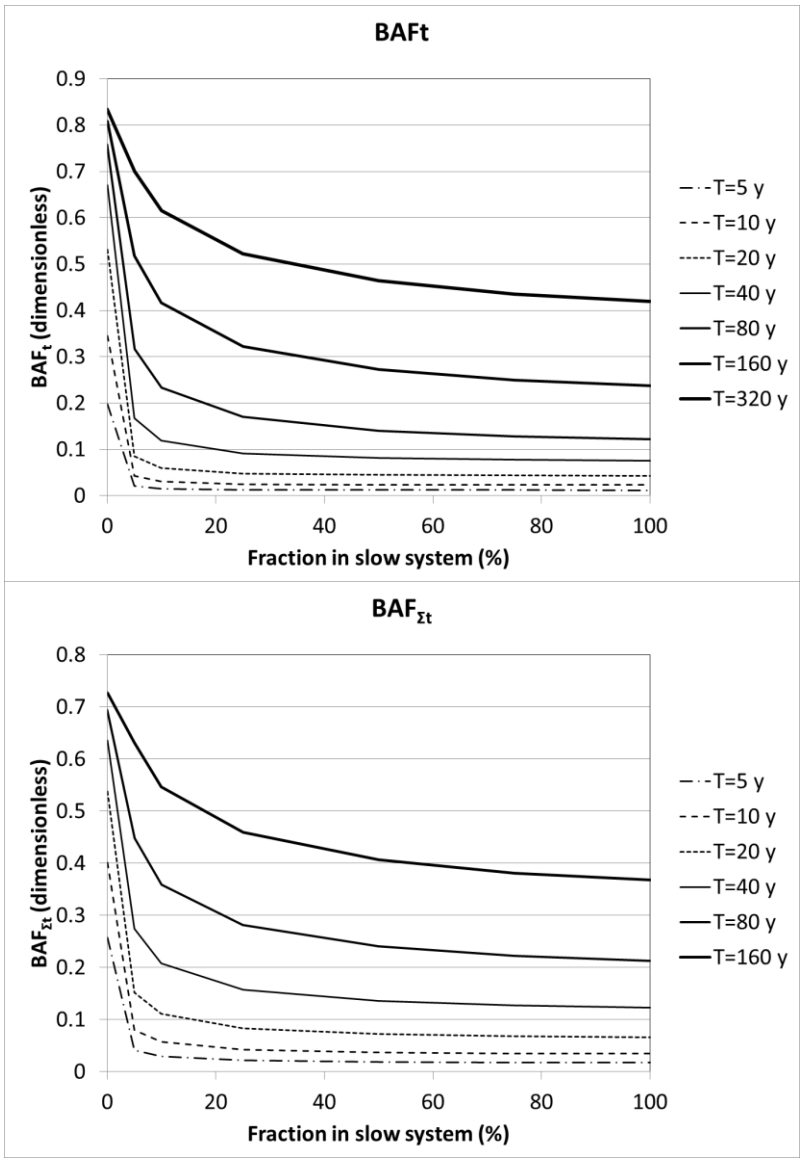

Figure F-7. Example of using the overall T based on a minimum flux to determine the cumulative BAF for systems with different values of T.