Alternative Framework
Deriving Net Biogenic Emissions (NBE) Using Land Carbon Stocks
Mark Harmon, 6-22-15

An alternative framework that would be transparent and intuitive to most everyone would be based on EPA's own words describing the basic question involved in the use of biogenic fuel stocks:

"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?"

The alternative framework could be expressed in annual (for time t) or in cumulative terms (for time period T). In addition, the framework would specify the boundary condition used to calculate the BAF, for example whether it included direct biophysical or indirect market effects or included atmospheric effects. The reason to specify the boundary condition is to avoid confusion and talking at cross purposes.

The basic formula to calculate the BAF would remain the same with the exception that any adjustments to the PGE related to losses in transport be separated from the NBE equation. The generic formula for BAF time interval T and boundary condition B would be:

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

Where NBE_{BT} and PGE_{BT} represent the cumulative and sum, respectively of the two terms over the period T. Specifically, the sum of potential gross emissions is:

$PGE_{BT} = \sum_{t=0}^{T} PGEt$

For a specific year t and boundary condition B the BAF equation would be:

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

Where NBE_{Bt} and PGE_{t} are the annual changes in NBE and the annual PGE for year t. Hence the only functional difference between the two formulae would be whether a period or an annual temporal resolution is used.

There would also be two versions of the NBE, both would be based on difference between a reference scenario (r) and a policy scenario (p) in terms of carbon stores and hence would directly answer the basic question raised by EPA. At the most aggregated level the NBE formula for time period T and boundary condition B would be:

$NBE_{BT}=TC_{rT}-TC_{pT}$

Where TC stands for terrestrial carbon and NBE_{BT} represents the difference in carbon stores between reference scenario (r) and the policy scenario (p) at the end of time period T. This and

all subsequent versions of the NBE equation are presented as a finite difference framework given that it unlikely the time step is likely to shorter than 1 year; however a calculus version similar to that presented by Dr. Reilly could also be used. The reason the policy scenario is subtracted from reference scenario is to provide the correct sign: a loss of carbon stores caused by the policy scenario would lead to a positive sign in NBE. Conversely a gain in carbon stores caused by the policy scenario would lead to a negative sign in the NBE.

If NBE is considered at an annual time step then the rate of change (Δ) in the difference in carbon stores between the reference scenario (r) and the policy scenario (p) at time t can be computed as:

$NBE_{Bt} = \Delta(TC_{rt} - TC_{pt})$

Expanded out this would be:

$\Delta(TC_{rt} - TC_{pt}) = (TC_{rt} - TC_{pt}) - (TC_{rt-1} - TC_{pt-1})$

which is the change in the difference scenarios r and p between time t and t-1. This means that when the difference between the two scenarios ceases to expand or contract NBE_{Bt} equals zero.

If a time step other than one year, for example 5 years, is used then it would be the rate of change over that period (e.g., Δ/5 years) instead.

The annual equation can be converted to a cumulative period T for boundary condition B as follows:

$NBE_{BT} = \sum_{t=0}^{T} \Delta(TC_{rt} - TC_{pt})$

Which sum of the annual change in difference in the stores each year t in terrestrial carbon over a total period of time T between the reference scenario (r) and the policy scenario (p) for boundary B. The advantage of this formulation over the version described above is that it can more adequately address situations in which the difference in stores is not described over time as a straight line. Moreover, if the boundary condition is expanded to include atmospheric effects, then the temporal pattern of net carbon release or uptake would be important to consider.

This formula could be subdivided to represent different sectors (i.e., agricultural, forest, waste, etc) or divided into major pools involving differ processes or controls. For example if one was calculating the cumulative effect on individual carbon stores over time period T for boundary condition B, the framework would consider the net change in carbon stores of live (CL), dead (CD), soil (CS), products (CP), waste pools (CW), and transportation loss (TL) pools.

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

Alternatively if there is no need to track the changes related to individual pools, then this could be rearranged to be:

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

Which is the sum of all the carbon stores of the policy scenario subtracted from that of the reference scenario.

While this expanded formulation includes multiple terms, in its most expanded version still contains one less than the current NBE formula and they are essentially analogous input-output subsystems. If the framework boundary is expanded to include fossil carbon substitutions then those could be added as well as an additional pool subject to inputs and outputs. Although these pools would have to be defined, the terms would be based on what the pools are and not where the pools came from or where they are going. These pools can be subdivided and rearranged as needed, but the key feature is that all the terms can be readily aggregated or disaggregated and still follow conservation of mass and be subject to mass balance. In addition all the terms would be analogous input-output systems despite the fact the actual processes leading to input and output would change. The new formula would be scale and process invariant as it could be used for a stand or plot, a fuel shed, and a region. It would apply to the system whether direct or indirect effects such as market signals are considered but would explicitly specify when the boundary conditions have been changed. In sum this formula would reduce unneeded complexity, be more direct, be transparent, and would be easily scalable.

Analytical solutions to NBE equations.

While simulation models could be used to estimate the temporal changes in NBE_{BT}, the fact that the formulation is based on pools that have inputs and outputs has major advantages and would allow one to intuitively check the sign and magnitude of NBE_{BT} without elaborate modeling. For example, 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 (Css):

$$O = k\, Css$$

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

$$Css = I/k$$

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

$$I/k > I/(k(1+n))$$

then there must be a loss of carbon in the system 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:

$$I/k = I(1+n)/(k(1+n))$$

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

$$I(1+n)/k > I/k$$

This might reflect the case of negative leakage in which new forest area is increased and effectively increases I.

Boundary Conditions

The alternative framework equations could be used for several boundary conditions:

Direct biophysical effects (DB) which would consider the effects of harvest on the area equivalent of the fuel sheds within a region.

Indirect effects mediated through market signals (IM) which considers responses outside the fuel sheds. Using this boundary condition would essentially deal with the leakage question without confounding pools or emissions with boundary conditions.

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

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

Subpools

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

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

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

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