Appendix B: Temporal Scale

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1. Introduction

The purpose of this appendix is to discuss considerations related to the treatment of time in possible applications of the framework. 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 accounting, because the choice of treatment may have significant impacts on the outcome of an assessment framework application. While there is no single, scientifically correct method for the treatment of time when assessing biogenic emissions, there are a number of options for incorporating temporal dynamics into an assessment of biogenic carbon fluxes. The choice of temporal assessment method could ultimately depend on the context of a specific framework application.

This appendix discusses various aspects related to assessing time-dependent effects in the production, processing, and consumption of biogenic feedstocks. Considerations related to time can include a variety of issues such as:

- Emissions horizons and reporting periods (i.e., fluxes related to feedstock production may occur over many years, whereas reporting may be the current year);
- Interplay with spatial scale (i.e., implications of larger scales and shorter time frames versus smaller scales and longer time frames);
- Baseline perspective (i.e., is the analysis forward- or backward-looking, or both?); and
- Differences in temporal characteristics of different feedstocks (i.e., annual crops, short rotation energy crops, and longer rotation forestry systems).

In general, accounting for temporal effects will be most significant when considering future potential fluxes related to long rotation feedstocks (e.g., roundwood), activities that affect the equilibrium storage in soil carbon pools, decay rates, or in cases of significant land use change, where biogenic feedstock production has implications for long-term emissions changes in terrestrial carbon stocks.

Given that different temporal perspectives could be used by the framework, two different baseline approaches are evaluated in this framework report: retrospective reference point and future anticipated baseline. These baseline approaches use aspects of time. The retrospective reference point baseline does not take into account future potential biogenic emissions fluxes related to biogenic feedstock production, processing, and use. The future anticipated baseline, due to its prospective nature, can take into account such future potential fluxes. As such, most of the discussion in this appendix focuses on potential methods for considering time in terms of a prospective analysis.

This appendix provides various illustrative treatments of temporal dynamics when activities and related emissions fluxes do not fit neatly into single assessment time periods. As presented in Section 4, illustrative treatments for prospective applications of the framework in this appendix include a frontloading approach, a year-to-year carryover approach, and an annualized carryover approach. A discussion of discounting time is provided in Section 5.

2. Key Temporal Scale Considerations

The production, processing, and use of biogenic feedstocks for energy can, in some circumstances, have emission effects extending into the future and there are different methods to and perspectives about how to assess future emissions trajectories (Dornburg and Marland, 2008; Fargione, 2008; Kendall et al., 2009; Levasseur et al., 2010; Walker et al., 2010; Cherubini et al, 2011; Mitchell et al., 2012; Helin et al., 2013; Walker et al., 2013; Miner et al., 2014). Accounting for these emissions appropriately in different policy contexts may necessitate various decisions that reflect the goals and parameters of the policy. An application of the framework presented in this report that includes assessment over time may need to identify emissions and assessment horizons, reporting periods, the appropriate baseline method, the appropriate spatial scale, and the temporal characteristics. These considerations are discussed below in more detail.

2.1. Emissions Horizon, Assessment Horizon, and Time of Reporting

An application of the framework that includes assessment over time may need to articulate how biogenic CO_2 emissions fluxes over time from biogenic feedstock production, processing, and use relate to stationary source biogenic CO_2 emissions in a single period (e.g., time of biogenic feedstock use or reporting). It is not only a question of how far into the future must an analysis look, but also how these emissions are accounted for and valued over time, and when are they accounted for or reported. Thus, it may be necessary to distinguish between the "emissions horizon" and the "assessment horizon." The emissions horizon is the period of time during which the carbon fluxes resulting from actions taking place today actually occur, while the assessment horizon is a period of time selected for the analysis of the carbon fluxes. In effect, these time horizons can differ significantly.

For example, the emissions horizon reflects all future estimated net carbon fluxes associated with the production and harvest or removal of a feedstock today. Therefore, the emissions horizon may need to span a year to several decades, depending on the feedstock and production site conditions, to account for all these effects. The assessment horizon, however, may be a specified time frame over which estimated future effects may be taken into account. For example, a specific policy may allow the inclusion of future potential effects over 20 years, whereas the estimated emissions horizon is 50 years. The time of reporting may be a one-time event or an annual event at the time or in the year in which the harvest/removed feedstock is consumed at the stationary source. When making determinations about time frame per policy or program needs, one should consider how to address these different time horizons. Illustrative general methods for reconciling these different horizons are discussed in Section 4.

2.2. Temporal Differences between Feedstocks

Biogenic carbon fluxes related to biogenic feedstock growth, harvest, and/or collection, feedstock production site soil carbon levels, and land use and/or management change do in many cases occur over a period greater than one year. The consideration of multiyear time dynamics for biogenic feedstock growth is particularly relevant for long rotation feedstocks or feedstocks where carbon stored in biomass accumulates over time subject to biological growth functions and where feedstock production and/or collection affect landscape soil carbon dynamics or other land use changes. For long rotation feedstocks, the amount of biogenic CO_2 emissions from harvest and combustion may take years to be sequestered on the same site from which it was harvested. For logging residues, analysts may need to consider decay and associated landscape biogenic CO_2 emissions. For example, the collection and combustion of logging residues result in an immediate release of biogenic CO_2 emissions that otherwise might have instead occurred in the form of CO_2 and CH_4 over a series of years through natural decomposition on the forest floor. Concurrently, removal of the logging residues can cause increased emissions through loss of soil carbon over time, while also altering rates of forest growth and carbon sequestration. Changing management practices can also potentially affect mineral soil carbon pools (Buchholz et al., 2013).

Time dynamics may also be a relevant consideration for some agricultural feedstocks. For example, land use change such as the removal of forests for agricultural feedstock production could result in an initial release of carbon that is not fully recaptured in subsequent use of the land for agriculture. Furthermore, cultivation of perennial bioenergy feedstocks such as switchgrass can lead to long-term increases in soil organic carbon relative to annual crops due to extensive root systems (belowground biomass) and reduction of tillage disturbances. Also, changing management practices, such as removing agricultural residues like corn stover, may reduce decay-related emissions but also reduce soil carbon inputs and thus long-term soil organic carbon stocks.

2.3. Interactions between Spatial and Temporal Scales

Temporal aspects of biogenic carbon fluxes can also depend on the choice of spatial scale. In some circumstances, assessing biogenic carbon fluxes at a small spatial scale for a long period of time can result in similar outcomes to those from considering a large spatial scale over a short period of time. For example, the harvest of a long-rotation feedstock, such as roundwood, on a significantly small spatial scale (e.g., plot or stand) will initially result in biogenic carbon emissions, but over enough time, replanted trees (e.g., assuming similar species, conditions) will sequester approximately the same amount of carbon that was released by the previous harvest. However, if that same amount of harvest is considered over a larger spatial scale (e.g., a stand within a region), the biogenic carbon emitted from the harvested stand will be balanced out by sequestration in that region from the continued growth of unharvested roundwood and any reforestation activities in the region over a relatively short time frame (likely shorter than regrowth of the stand itself).

2.4. Temporal Differences between Baselines

The retrospective reference point baseline and future anticipated baseline approaches both include treatments of time. However, the way in which these two baseline approaches consider time is markedly different. The retrospective reference point baseline approach is inherently backward-looking (because it evaluates measured or modeled emissions fluxes over a specific time frame in the past), while the future anticipated baseline approach is inherently forward-looking (because it evaluates points in time along different future simulations).

When the reference point baseline approach is applied retrospectively, it takes into account net atmospheric biogenic CO_2 contributions associated with biogenic feedstock production on the landscape by assessing differences in biogenic stocks and flows between two points in time in the past. Under this baseline approach, one must decide which specific reference points in time to use, including the length of time between reference points (e.g., 5, 10, 15 years, or other?) and the location of the points in the chosen time horizon (e.g., at what point in time was data first collected, when were the most recent data produced?). Integration of future multiyear fluxes (e.g., from potential decay, soil carbon equilibrium changes) is not necessary when values for framework terms are derived through a backward-looking approach (i.e., the retrospective reference point baseline). Appendices H and I show illustrative equation term calculations and case study applications for forest- and agriculture-derived feedstocks using the retrospective reference point baseline approach.

The future anticipated baseline approach assesses the estimated net change in carbon stocks between two projected future scenarios at the same specified point in time, that is, between a business-as-usual (BAU) scenario and an alternative scenario with changes in estimated environmental, economic, and/or policy conditions (e.g., Searchinger et al., 2009). Because this baseline approach can be used to project future biogenic carbon-based fluxes associated with biogenic feedstock production, processing, and use, there are more considerations about how to represent and incorporate elements of time into such an analysis than in the retrospective reference point approach. Integration of future multiyear fluxes (e.g., from potential decay, soil carbon equilibrium changes, other land use and/or management change effects) may be necessary for framework terms representing biogenic landscape attribute values (*GROW, AVOIDEMIT, SITETNC*, and *LEAK*, if included) and possibly process attributes (depending on treatment of biogenic carbon losses through the supply chain, including storage losses or carbon stored in final products, as captured by the *L* and *P* terms). Appendices J, K, and L, respectively, discuss future anticipated baseline considerations, possible baseline construction methods, and illustrative forest- and agriculture-derived feedstock case study applications using this baseline. Waste-derived feedstocks, as discussed in detail in Appendix N, are assessed in this report by using potential alternative pathways and related GHG pathways for those materials, which in many cases include consideration of future potential methane emissions from decomposition if not used for energy.

3. Illustration of General Temporal Dynamics Using Decay Rates

The magnitude of an emissions pulse (meaning, in this context, the cumulative biogenic carbon-based emissions over a time period) may depend on how far into the future an analysis is extended. In theory, one could look as far into the future as required to physically account for a multiyear carbon flux (i.e., the entire emissions horizon over which the flux occurs). In practice, however, a shorter time frame may be warranted in specific accounting circumstances, especially if the fluxes toward the tail end of a multiyear flux pattern are very small or a specific program or policy application necessitates a specific, shorter time frame.

To simply explain the general dynamics of time, this appendix uses concepts called the "Fraction of Carbon Remaining" (FCR_t) and "Fraction of Carbon Emitted" (FCE_t) to illustrate the implications of different choices of time frame when assessing emissions flux dynamics over time (t). Using the specific context of natural decay from logging residue feedstock as an example, FCR_t is the amount of carbon that remains (in terms of $mtCO_2e$) on the site (CR_t) after a particular time frame divided by the magnitude of the original carbon pool (CR_0), assuming a particular decay rate:

$$FCR_t = \frac{CR_t}{CR_0} \quad \textbf{(EQ. B.1)}$$

Where:

$$CR_t = CR_0 \times (1 - decay\ rate)^t \quad \textbf{(EQ. B.2)}$$

FCE_t is calculated as:

$$FCE_t = 1 - FCR_t \quad \textbf{(EQ. B.3)}$$

FCR_t and FCE_t are unit-free (i.e., dimensionless) values by their definitions. Table B-1 provides examples of the impact of different accounting time frames on the emissions pulse accounting (i.e., FCE_t over the defined time period) from the natural decay of 1 $mtCO_2e$ woody residue feedstock left onsite. Note that these are not emissions due to biogenic feedstock harvest or consumption, but emissions related to decay of the logging residue if left onsite. The representative values presented in Table B-1 and depicted in Figure B-1 illustrate the fraction of carbon emissions over three time frames: 20 years, 30 years, and 100 years.

Table B-1 shows that for a low decay rate of 5% loss per year, 64% of the biogenic CO_2 is emitted over 20 years, whereas 99% of the biogenic CO_2 is emitted over 100 years. However, for a high decay rate of 25% loss per year, nearly all biogenic CO_2 is emitted within the first 20 years.

Table B-1. Theoretical Illustration of How the Impact of Time Depends on the Natural Decay Rate and Time Period

Loss/Year (decay rate)	Cumulative FCE Time Period (t)		
	20 years	30 years	100 years
5%	0.64	0.79	0.99
10%	0.88	0.96	1.00
25%	1.00	1.00	1.00

Figure B-1 illustrates the annual and cumulative FCE, as well as the FCR, over a 100-year time frame using a 5% annual decay rate assumption.

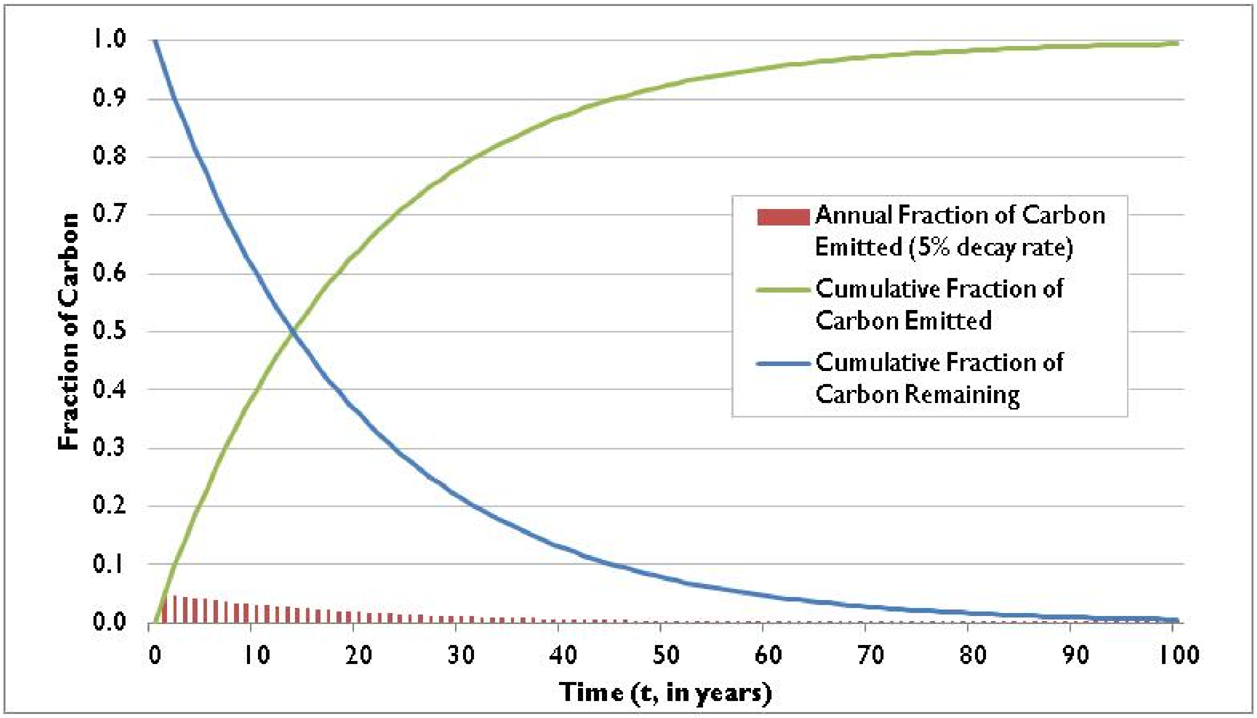

Figure B-1. Annual Fraction of Carbon Emitted (FCE), Cumulative Fraction of Carbon Emitted (FCE), and Fraction of Carbon Remaining (FCR), Dependent on the Decay Rate and Time Period.

4. Potential Methods for Assessing Multiyear Fluxes

In terms of the *BAF* equation, the assessment treatment of multiyear carbon fluxes within a prospective analysis allows for the estimation of biogenic CO_2 emissions associated with certain feedstocks (i.e., woody biomass) with slow rates of natural decay (in the case of residues or fallen trees) and/or long growth periods (referred to generally as "long-rotation" feedstocks). However, accurately capturing these multiyear landscape effects related to feedstock production, processing, and use can be challenging in the context of an assessment framework application that may need to estimate and report annual biogenic CO_2 emissions from a stationary source.

Various terms in the *BAF* equation (*AVOIDEMIT, GROW, SITETNC, LEAK*, if included, and possible losses within the *L* term) can represent biogenic CO_2 fluxes that have a temporal dimension longer than an annual cycle for certain feedstocks and, thus, may require application of an accounting method for these temporal effects. The *GROW* term, for example, represents the projected change in biogenic carbon fluxes from feedstock growth in a given area over a given time period.[1] The *SITETNC* term reflects estimated site-induced changes in above- and belowground carbon that typically occur over a multiyear period due to a direct land use or land use management change that triggers changes in carbon stocks. Similarly, the *AVOIDEMIT* term accounts for the avoidance of estimated biogenic emissions that could have occurred on the feedstock landscape without biogenic

[1] Note that under the retrospective reference point baseline approach in a regional application, *GROW* is calculated as recent growth in the region where the feedstock is produced and not in terms of future regrowth over time.

feedstock removal (e.g., avoided decomposition, which also may occur over a year, multiple years, or decades depending on the feedstock) or per an alternative management strategy (e.g., waste-derived feedstocks). *LEAK* represents leakage effects that can occur from feedstock production, including indirect land use changes that could affect landscape CO_2 fluxes for years into the future. Feedstock losses captured in the *L* term may be used to reflect decomposition of feedstocks in storage or other processing along the supply chain.

Each approach to time discussed below integrates future multiyear carbon flux values (i.e., carbon emissions and/or sequestration that occur over multiple years) into an annual accounting framework (meaning net emissions are reported/calculated annually) for illustrative purposes. Note that the need to integrate future multiyear fluxes is necessary only when a specific application of the framework allows for or requires consideration of counterfactual or future emissions fluxes related to biogenic feedstock production activities. Again, it is not necessary to integrate these forward-looking temporal elements when values for accounting terms are derived through a retrospective reference point baseline approach.

The three potential approaches for incorporating multiyear carbon fluxes into the framework are presented in this section. These concepts are for illustrative purposes and do not present an exhaustive list of how temporal aspects could be treated in a framework application. These illustrative temporal accounting approaches are (1) front loading; (2) year-to-year carryover; and (3) annualized carryover. Another approach, discounting, is discussed in a separate section below. The frontloading approach sums all future estimated net emissions associated with biogenic feedstock production and accounts for them in the time period the biogenic feedstock is used. Under the year-to-year carryover approach, emissions are tracked over time and recorded as a cumulative amount as they occur over time. Under the annualized carryover option, estimated cumulative emissions fluxes are annualized over a specific time period (which can be the time frame in which the emissions impacts are expected to occur or some other determined time frame).

The basic advantages and disadvantages associated with each of these options are discussed below. It is important to note that none of these three approaches involve discounting as presented here. This means that net biogenic CO_2 fluxes that occur many years in the future are treated identically as net emissions that occur in the present in all methods discussed below. However, discounting could be utilized in conjunction with any of the three approaches outlined below (the last section of this appendix discusses discounting). Lastly, the methods below include some estimation of future conditions and related emissions fluxes, which may over- or underestimate future emissions fluxes relative to actual emission fluxes trajectories that come to pass.

4.1. Front-Loading

With the front-loading approach, consideration is given to all the biogenic carbon fluxes that will occur over some period of time (which could be the estimated emissions horizon or some other specified period such as, for example, 20 years, 30 years, or 100 years) as a result of a particular biogenic feedstock production activity in the current time period (for example, a land use change or residue removal). Then, these emissions fluxes can be summed over time for a cumulative estimate. These fluxes are then accounted for in the current period, or period when the feedstock is used (or reported), in units of CO_2e per ton of feedstock. In this way, the total carbon fluxes associated with a particular unit of feedstock production are accounted for up front, before the estimated future emissions/sequestration associated with that unit of feedstock actually occur.

Under the front-loading approach, multiyear net biogenic carbon fluxes are accounted for over a specific time frame but attributed to a single (annual or other defined reporting) time period. The approach captures all of the present and future estimated net emissions associated with growth, harvest, decay, and/or land use changes related to the biogenic feedstock production, processing, and use. Also, economic discounting could be incorporated into the front-loading approach if it is determined that future carbon fluxes should not be treated the same as current fluxes, or if discounting is appropriate in a specific policy or program application of the framework.

Figure B-2 illustrates the calculations of FCE_t under the front-loading approach in the context of logging residues. For a 100-year accounting period, the front-loaded FCE_t is the sum of annual FCE_t values over 100 years. In this case, the front-loaded FCE_t equals 0.99.

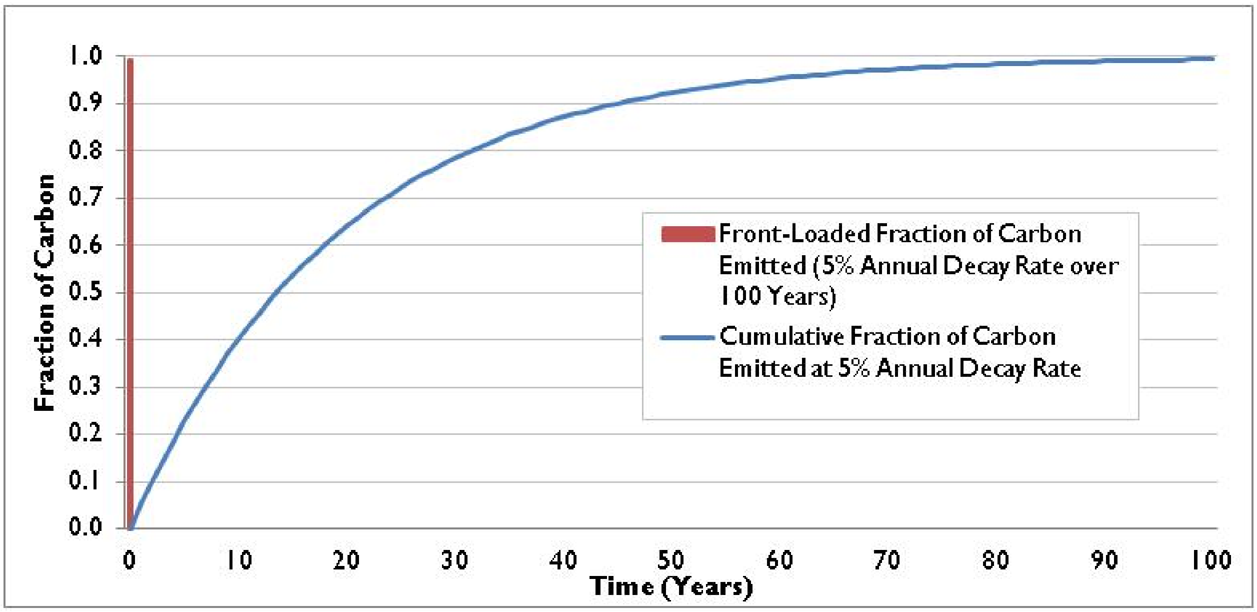

Figure B-2. Cumulative FCE and Front-loaded FCE with a 5% Loss per Year Assumption over 100 Years[2].

There may be policy applications or other framework applications in which the assessment horizon is shorter than the emissions horizon. For instance, the emissions horizon for certain feedstock production effects is 75 years, but the time frame for analysis is only 50 years. In such a circumstance, all the estimated future net effects may not be included in an analysis using this approach.

This basic method for incorporating temporal dynamics is relatively straightforward in that all or a portion of the estimated future net biogenic CO_2 emissions fluxes are accounted for in a single time

[2] The sum of the annual FCE values over 100 Years is the front-loaded FCE over a 100-year accounting period.

step. However, there are inherent uncertainties related to future socioeconomic and biophysical projections and related trajectories of estimated net emissions fluxes related to the biogenic feedstock production and use. Also, if all estimated future emissions effects are captured in the current time period or when the biogenic feedstock is utilized, for some feedstocks this could be a relatively large assessment factor, which could discourage use of that biogenic feedstock.

4.2. Year-to-Year Carryover

In the year-to-year carryover accounting method presented here, the biogenic CO_2 fluxes associated with a unit of feedstock production in the current period are accounted for in the year in which the fluxes actually occur. For example, land use change that occurs during the production of this year's biogenic feedstock might generate a small increase in soil carbon sequestration each year for the subsequent 20 or 30 years. In this accounting approach, the accounting for the subsequent annual increment of change in emissions occurs in the year of the emissions change.

In the year-to-year carryover accounting approach, net emissions from feedstock production for a given year are reported in the same year that those emissions occur. Any net carbon fluxes carried over from feedstock utilization in previous years are also included. For example, if a feedstock removed from a site in year t triggers fluxes of emissions to and from the atmosphere over subsequent n years, the magnitude of the fluxes is projected n years into the future. The fluxes would then be accounted for in the future, in the year ($t + 1$ year, $t + 2$ years, $t + 3$ years … up to $t + n$ years) in which they actually occur. Under the year-to-year carryover accounting approach, the emissions horizon is the same as the assessment horizon. Thus, an entity may be accounting in a given year for carbon fluxes associated with biogenic feedstocks used over multiple prior years (the number of years depends on the time frame chosen).

The carryover approach may increase the complexity of accounting requirements that would need to be implemented by stationary sources and program administrators. Under the year-to-year carryover approach, multiple terms in the framework may change from one year to the next, thereby complicating the calculations. Also, economic discounting could be incorporated into year-to-year carryover if future carbon fluxes should not be treated the same as current fluxes or if discounting is appropriate in a specific policy or program application of the framework.

Figure B-3 illustrates the annual FCE_t year to year over a 100-year time frame using assumptions of 5, 10, and 25% emissions per year in the case of logging residues. The annual FCE is calculated by subtracting each year's FCR_t value from the previous year's FCR_t value. As an example using a 5% loss per year, in Year 1, 95% of the carbon is remaining and is subtracted from the prior year (100%), which gives 0.05 as the annual FCE_t in Year 1. The representative values depicted in Figure B-3 illustrate that the annual FCE_t in a particular year depends on the actual time profile (i.e., decay rate) of the emission pulse.

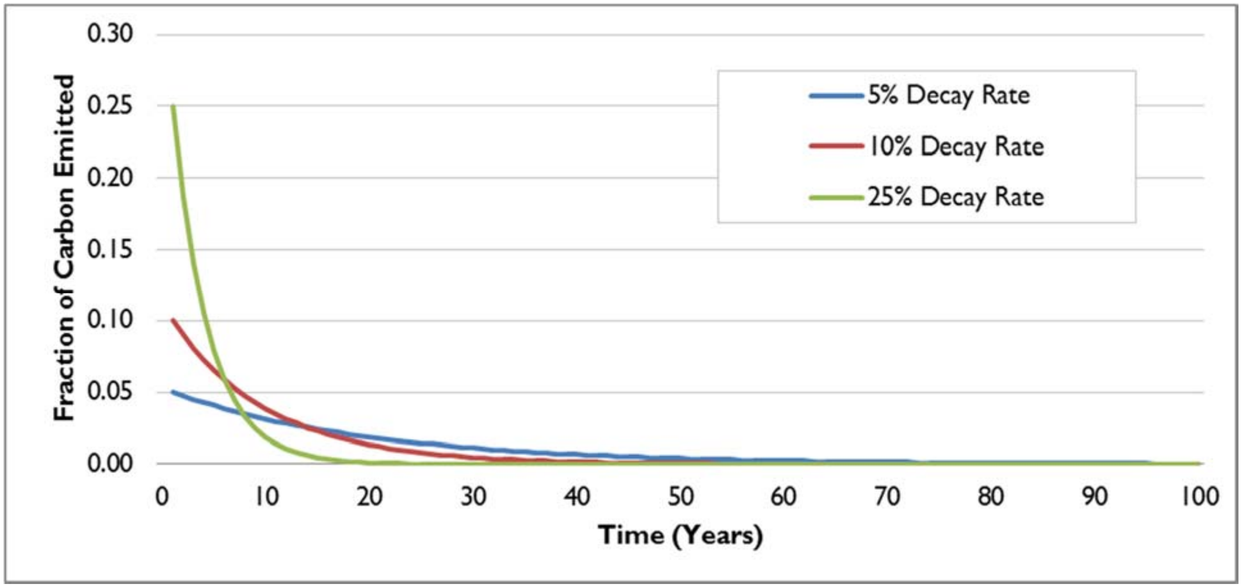

Figure B-3. Year-to-Year Annual Fraction of Carbon Emitted (*FCE_t*) Depends on the Decay Rate.

This method could allow for future estimated biogenic CO_2 fluxes related to the use of a feedstock to be reflected in the values for framework equation terms as they occur on the landscape rather than during the year of feedstock use. Also, this method permits updates to future trajectories of estimated emissions fluxes related to the biogenic feedstock production and use in case initial estimated trajectories prove to differ from actual emissions flux trajectories. However, the values of framework equation terms for a given year's feedstock use may change over subsequent years, which may cause market and investment uncertainty (the *BAF* can be applied only to the annual emissions from a stationary source in a given year, which can vary).[3] As a result, adjustment of future-year stationary source biogenic CO_2 emissions may not capture and represent the actual net emissions impact (on a tonnage basis) of future-year carbon fluxes related to previous-year feedstock consumption.

4.3. Annualized Carryover

The annualized carryover approach accounts for cumulative emissions over the emissions horizon and then divides those emissions equally over the assessment horizon. Thus, values for future estimated annual net emissions are equal across the assessment horizon and are determined by the annualized value. Depending on the dynamics of the biogenic CO_2 processes on the landscape, annualized carryover may over- or underestimate the fluxes at the start of the accounting period compared with year-to-year carryover accounting. The illustrative examples of annualized carryover in this appendix do not include economic discounting. However, economic discounting could be incorporated into this approach in applications of the framework where future biogenic CO_2 fluxes were not be treated the same as current fluxes. It is possible that a specific policy or

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[3] If both the *BAF* and emissions varied each year, then these two factors introduce uncertainty into the annual emissions estimate, making it difficult for a stationary source to have stability for investments.

program application of the framework would discount future biogenic CO_2 fluxes (discussed in Section 5).

Under the annualized carryover approach, the values of future estimated annual net emissions for each year's feedstock production are the same. The time-related values for relevant *BAF* equation terms would remain the same over time (or until recalculated based on new reference data) and provide simplicity for application of the *BAF* equation. However, because future net emissions effects related to a current year's consumption of feedstock are accounted for in future years, applied accounting complications could arise. For example, as with year-to-year carryover accounting, future fluxes related to previous years' feedstock consumption would need to be applied in each year when calculating a stationary source's *BAF* related to the use of a feedstock. If the stationary source changes ownership or operating status, properly transferring the accrued future emissions accounting values related to past feedstock consumption may prove complex.

To illustrate these dynamics, Table B-2 presents the annualized FCE_t over a 100-year emissions horizon for a representative multiyear carbon flux related to forest residue decay, with different percentage carbon loss assumptions and different assessment horizons. To calculate annualized FCE_t for a 100-year emissions pulse, cumulative emissions up to 100 years were divided by 20-, 30-, and 100-year time periods, respectively (e.g., annualized FCE_t for a 5% decay rate over a 20-year assessment horizon is 0.99 divided by 20, which equals 0.05).

Table B-2. 100-Year Emissions Annualized over 20-, 30-, and 100-Year Assessment Horizons.

Loss/Year (decay rate)	Annualized FCE (100-year emissions)		
	Time Period (t)		
	20 Years	30 Years	100 Years
5%	0.05	0.03	0.01
10%	0.05	0.03	0.01
25%	0.05	0.03	0.01

Table B-3 presents a truncated annualizing approach where the emissions horizon is truncated at 20, 30, and 100 years. The cumulative emissions after 20, 30, and 100 years are then divided equally over the same time periods. Under the truncated approach, not all of the estimated emissions are captured, and the assessment horizon is the same as the truncated emissions horizon (20, 30, and 100 years in this case). These time periods were chosen to represent different assessment horizons (e.g., facility lifetimes) that could be applied in practice. For example, the annualized FCE_t for truncated emissions at 20 years for a 2% carbon decay rate is 0.33 divided by 20, which equals 0.02.

Table B-3. 20-Year, 30-Year, and 100-Year Emissions Annualized over 20-, 30-, 100-Year Time Periods, Respectively.

Loss/Year	Annualized FCE [truncated emissions]		
	Time Period		
	20 Years	30 Years	100 Years
5%	0.03	0.03	0.01
10%	0.04	0.03	0.01
25%	0.05	0.03	0.01

The representative values in Table B-2 illustrate that in determining appropriate emission annualized values, it is important to consider both the emissions horizon for the feedstock effects as well as the assessment horizon for the reporting of those emissions. Specifically, annualized emissions increase as the emissions horizon increases; for example, under a 5% decay rate the non-truncated annualized FCE_t for a 100-year emissions horizon and 20-year assessment horizon (0.05) is greater than the truncated annualized FCE_t for a 20-year emissions horizon and 20-year assessment horizon (0.03). However, as the assessment horizon increases, annualized emissions decrease: for example, under a 5% decay rate the non-truncated annualized FCE_t for a 100-year emissions horizon and 100-year assessment horizon (0.01) is less than the non-truncated annualized FCE_t for a 100-year emissions horizon and 20-year assessment horizon (0.05).

This method for accounting for time allows for inclusion of all emissions fluxes over the emissions horizon within the assessment horizon. Also, similar to the year-to-year carryover approach, this method can allow updates to future trajectories of estimated emissions fluxes related to biogenic feedstock production activities and use in case initial trajectories prove to differ from actual emissions flux trajectories. However, similar to the year-to-year approach, framework equation term values for a given year's feedstock use may change over subsequent years, which may cause market and investment uncertainty. The *BAF* can be applied to the annual emissions from a stationary source in a given year, which can vary.[4] As a result, adjustment of future-year stationary source CO_2 emissions may not capture and represent the actual net emissions impact (on a tonnage basis) of future-year carbon fluxes related to previous-year feedstock consumption.

4.4. Temporal Scale of the Illustrative Future Anticipated Baseline Approach in the Technical Appendices

When using a future anticipated baseline, integrating time into the assessment of forward-looking phenomena is inherent in the approach, and decisions about temporal dynamics may affect the outcomes (as discussed in the previous subsection). The future anticipated baseline approach as generally discussed in this report could conceptually apply whatever future time horizon is necessary for the specific program or policy analysis at hand. This report does not apply the framework to specific policies or programs and thus has no specific temporal parameters such as

[4] If both the *BAF* and emissions varied each year, then these two factors introduce uncertainty into the annual emissions estimate, making it difficult for a stationary source to have stability for investments.

an assessment horizon or time of reporting. For illustrative purposes in the technical future anticipated baseline appendices of this report (Appendices J, K, and L), the year-to-year carryover is applied using a 50-year simulation horizon. This assessment time scale is long enough to capture significant carbon dynamics of longer rotation feedstock species, land use and land use management changes, and soil carbon pools. Conversely, it is short enough to detect significant biogenic CO_2 fluxes related to biogenic feedstock production and harvest. The year-to-year carryover approach is used to show how estimated future net biogenic CO_2 emissions fluxes could change over time and to provide insights about the potential future impacts of biogenic feedstock production, processing, and use. In addition to annual accounting using the year-to-year carryover approach, one can also use this approach to evaluate cumulative emissions for a specific time horizon. Additional discussion of periodic (flux based) and cumulative landscape emissions projections using the year-to-year carryover approach can be found in Appendices K and L.

5. Discounting and Its Relevance to the Framework

Broadly speaking, there is a value to time. For example, benefits and costs are typically valued higher if they are experienced sooner (OMB Cir A-94). This value of time is usually discussed as a "discount" of what the future holds. Discounting is regularly applied in finance and economics, where it represents the time value of money, and quantitative values can generally be assigned. Discounting allows for assessment of the future value in today's terms (i.e., the *net present value*). To compute net present value, it is necessary to discount future benefits and costs. The discount rate is the interest rate used in calculating the present value of expected yearly benefits and costs (OMB Cir A-94).

For example, money invested today will accrue interest, and the quantity of money will grow over time according to the interest rate. Similarly, a debt will increase over time according to the interest rate. Money received today has more value than the same amount of money received in the future. If the interest rate is known, the net present value of future costs (e.g., the monetary value of building and maintaining seawalls) can be calculated, as can the future value of benefits (e.g., the monetary value of homes and tourism on the seashore). In other words, the net present value of future costs and benefits can be calculated by multiplying the costs and benefits in each future year by a discount factor, then summing all values over the lifetime of an investment, policy, or decision.

Discounting the value of damages associated with GHG emissions, which span multiple generations, is particularly complex and raises difficult and controversial questions of science, economics, philosophy, and law. The U.S. federal government reviewed the literature on intergenerational discounting several years ago when developing estimates of the social cost of carbon, i.e., the monetized value of damages associated with a marginal change in CO_2 emissions. The federal government found that although it is well understood that the discount rate has a large influence on the current value of future damages from GHG emissions, there is no consensus about what rates to use in this context.

Recognizing the lack of consensus about an appropriate intergenerational discount rate and uncertainty regarding how interest rates might change over time, the federal government selected three rates to span a plausible range of certainty-equivalent constant discount rates: 2.5, 3, and 5%

per year. In sum, average returns on longer-term investments were used to inform selection of certainty-equivalent discount rates. The federal government viewed this approach as defensible and transparent given its consistency with current benefit-cost analysis principles as well as OMB's guidelines for such analysis as embodied in OMB Circular A-4. The Technical Support Document, *Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866*, discusses this analysis in detail (Interagency Working Group, 2010).

The federal government has continued to research alternative approaches for intergenerational discounting. In particular, a group of world-recognized experts convened at an EPA-funded workshop in 2011[5] to explore what principles should be used to determine the rates at which to discount the costs and benefits of regulatory programs when costs and benefits extend over very long horizons. The charge questions that were the subject of the workshop discussion focused on three main areas: (1) whether and in what context it is appropriate to apply a Ramsey discounting framework in an intergenerational setting; (2) whether and how to directly estimate discount rates over long time horizons; and (3) how to apply discounting in a regulation where some costs and benefits accrue intra-generationally while others accrue inter-generationally. Notably, the group reached consensus that there are compelling arguments for using a declining discount rate schedule, though determined that practical questions remain regarding how to establish and implement such a schedule (Arrow et al., 2013).

Discounting is more challenging when applied to nonmonetary quantities where there is not a clear interest rate, thereby making it difficult to quantitatively equate present and future events. If the discount rate is known in the context of avoiding future climate change impacts, the net present value of future costs (e.g., the monetary value of damages associated with climate change impacts) can be calculated, as can the future value of benefits (e.g., the monetary value of avoided damages or avoided GHG emissions.) Also, if carbon emissions have monetary value as determined through a carbon tax, a cap-and-trade system, an emissions limit or permit system, or through the structure of the damages caused, then quantitatively discounting the value of emissions is more straightforward. However, discounting becomes more challenging when the quantitative links between physical emissions and costs or benefits are less clear.

The traditional role of discounting is to compare the costs and benefits of quantities (such as money or the monetary value of CO_2 emissions) that occur at different periods in time. The higher the discount rate, the lower the present value of the future unit (money, carbon etc.) in the future. This means that a high discount rate implies a strong time preference, such that events in the future, for example, are given far less value than those occurring today. Failure to discount future events assumes a discount rate of 0 and implies no time preference; that is, a 0 discount rate assumes that future events have the same value as current events. For carbon accounting, the fundamental issue is whether carbon emissions (or sequestration today) are valued the same as carbon emissions (or sequestration in the future), and how the valuation of time is factored into carbon accounting. For example, if one ton of CO_2 is emitted this year and one ton of carbon is sequestered 20 or 100 years from now, the treatment or valuation of time will determine if these events are of equal and

[5] Link to workshop summary: http://rff.org/Events/Pages/Intergenerational-Discounting-Workshop.aspx

opposite value so that the net effect is 0 or not. It is clear that time is important, but the challenge lies in how to deal with this preference quantitatively.

5.1. Time Preference in CO_2 Emissions

As mentioned above, one of the current challenges in carbon accounting is the time value of carbon emissions (or sequestration). Do emissions at some time in the future have the same value as emissions now? Does the time path of emissions and sequestration matter? Is there value in delaying emissions? Is there value in temporary storage of emissions if they will be released later? The importance of the time value of carbon has been recognized for many years (e.g., Richards, 1997), but there continues to be much debate on how to deal quantitatively with time and what the "appropriate" discount factor is in the context of monetizing future GHG emissions. A recent advisory group to the California Air Resources Board struggled with this topic without reaching consensus but did provide the consensus statement that "the timing of emissions [is] important and, as a general goal, policy should differentiate based on timing where possible" (Martin, Kloverpris, Kline, Mueller, & O'Hare, 2011, p.48). The group also concluded that there is "no intellectually supportable escape from the universally demonstrated judgment of society that consequences occurring at different times must be valued with reference to the time of occurrence," but the group acknowledged the difficulty of determining appropriate discount rates (Martin et al., 2011, p.27). Similarly, an EPA (2010a) publication on economic analyses discusses approaches for dealing with time without ending up with a quantitative conclusion but recommends that analyses "display the time paths of benefits and costs as they are projected to occur over the time horizon of the policy…"

The prevailing view is that physical carbon flows should not be discounted as a function of time but that—where carbon flows have economic value—the monetary value of the flows should be discounted. As O'Hare et al. (2009) wrote in a paper on their view of the proper accounting for time in biofuels analyses, "the discounting model applies to costs and benefits, not to physical phenomena that generate them, unless their economic value is otherwise stable over time" (p. 3) and "before such economic analysis can be meaningfully pursued the relationship between the physical and economic quantities must be established" (p. 4). If carbon emissions were currently subject to taxation, for example, the tax rate would be the economic value of reducing (or avoiding) emissions and possibly used as a discount rate in net present value calculations. The concept of applying a discount to a physical measure, however, is difficult to rationalize: a ton of carbon is a ton of carbon, and differences arise only from its equated economic value.

Any program or policy that considers effects of carbon emissions over time will need to decide on the applicability of valuing these emissions and, if done monetarily, how to discount them. One recent example of this decision-making process can be found in the Renewable Fuel Standard Program (RFS2) Regulatory Impact Analysis (EPA, 2010b). When considering how to measure the lifecycle GHG emissions from a given type of renewable fuel relative to a 2005 petroleum baseline, two important elements were considered in terms of how to estimate the stream of emissions and benefits over time: (1) the time period considered and (2) the discount rate applied to future emissions. Although a range of options was considered in the proposed rule, for the final rule EPA chose a 30-year time period and a 0% discount rate. Although a relatively short time period of 30 years was chosen because it was similar to the life span of a biofuels-producing facility, a discount rate of 0% was chosen "due to the many issues associated with applying an economic concept to a physical parameter" (p. 423). This is primarily because the Energy Independence and Security Act (EISA) of 2007 did not establish any monetary valuation of carbon emissions for the RFS2 program, as well as the "lack of consensus as to the appropriate discount rate to apply to GHG lifecycle emissions streams through time" (EPA, 2010b, p. 423).

The peer review report *Methods and Approaches to Account for Lifecycle Greenhouse Gas Emissions from Biofuels Production over Time* (EPA, 2009) is particularly direct in its opposition to discounting physical emissions, stating that "all reviewers noted in some way that a discount rate should only be applied to a monetary unit, rather than a physical unit such as a carbon emission." Similarly, "proper discounting ... can only be conducted on value (i.e., damages, not physical quantities such as emissions)" (p. B-2) and "discount rates are only justifiable when applied to monetary impacts, not physical impacts" (p. 13). Further, "economic discounting cannot logically be applied to physical quantities such as GHG emissions, only to economic quantities such as climate change damages" (p. B-4). Similarly, Martin et al. (2011) wrote that "in the absence of agreement on…values, discount rates become meaningless" (p. 27) and that when considering discounting, "a prerequisite is to begin with a monetized value to discount" (p. 26). Other sources, such as the Interagency Review on Social Cost of Carbon (Interagency Working Group, 2010) and Johnson and Hope (2012), do not address the concept of discounting physical emissions and focus on damages, costs and benefits, or other concepts of monetized value.

Although the literature is generally opposed to the concept of discounting physical emissions, some sources do discuss related instances where the strategy may be applicable. First, as noted by a few respondents in the peer review report mentioned above (EPA, 2009), discounting physical emissions may be appropriate if these emissions are used as a direct proxy for damages. Discounting is "justifiable if physical emissions were being used as a proxy for economic damages associated with warming" (p. 15) and only in this case are discount rates used for physical carbon units "analogous to monetary discount rates" (p. 22).

A number of recent efforts have attempted to describe a time-dependent damage function for emissions, that is, efforts to link emissions to atmospheric concentrations and subsequently to the climatic effects (damages) of increasing concentrations. This approach encompasses more than a time preference, because it can include recognition of the dynamics of changing marginal damages over time (i.e., the notion that the climate impact of one ton of CO_2 emissions today is not equal to the impact of one ton of emissions in the future because of factors such as the persistence of GHGs in the atmosphere, options for mitigation, or damages that are a function of the total level of atmospheric CO_2 at the time). Whereas traditional time preference should result in a decreasing importance of future emissions, equating emissions with damages could result in increasing importance of future emissions if the damage function is increasing faster than the rate of time preference (see, for example, Richards, 1997). As characterized by Marshall (2009), "Ideally, a GHG accounting method … should explicitly analyze the expected damage associated with flows over time. The corresponding monetary units associated with this damage can then be discounted to determine how the impacts of future flows compare to those of the present." Fargione wrote that "if

EPA is not willing to make assumptions about the relationship between emissions and damages, then they should not use any discounting" (EPA, 2009, p. B-4).

Papers by O'Hare et al. (2009) and Cherubini et al. (2011), for example, calculate cumulative radiative forcing (described by O'Hare et al. as "a physically plausible proxy for the total damage to the planet from the CO_2 emissions") or GWPbio (defined by Cherubini et al. as "the effective climate impact") in efforts to describe a damage cost that reflects the time path of CO_2 emissions. Similarly, Kendall et al. (2009) propose a "time correction factor" to "properly account for the timing of … greenhouse gas emissions in the biofuels life cycle" (see also Alissa Kendall & Price, 2012). Levasseur et al. (2010) describe a dynamic life-cycle analysis that considers the time value of emissions. Conceptually, discounting marginal damages is related to traditional discounting in that it makes assumptions about changing values over time, but in this case, the "value" is expressed in terms of the impact on climate.

Ultimately at least three factors enter into considering the time dependence of the value of carbon flows: (1) the monetary values potentially captured in cost-benefit analyses (as discussed above); (2) the existence of irreversibilities or tipping points (see, for example, Kolstad, 1994); and (3) the role of learning (see, for example, Kolstad, 1993). On tipping points, Marshall (2009, p.9) wrote, "the potential for irreversible change is one of the significant determinants of the expected damage function for GHG emissions that must be considered in determining how to compare current to future emissions, and is one of the most convincing arguments for the need to make some sort of distinction between current and future … emissions." Kolstad (1994) includes the investment capital of mitigation measures as an irreversibility. On the role of learning, Kolstad (1993) notes the role of uncertainty in the relative value of current and future emissions and concludes that "accelerated learning tends to reduce current period optimal emissions." That is, rapid reductions in uncertainty tend to reduce, but not eliminate, expenditures to reduce current emissions as uncertainty is being resolved. Dornburg and Marland (2008) raise many of these issues in the context of the value of temporary carbon sequestration or of delaying emissions.

Uncertainty becomes a dominant factor in attempting to discount future emissions (or sequestration) when significant time intervals are involved in lifecycle analyses or the impacts of land use change. Despite recognition of the importance of dealing with the time value of CO_2 emissions, there is great uncertainty in the appropriate value of a discount rate. This uncertainty is due to uncertainty about the future, uncertainty about the correct relationship between emissions and damages, and the potentially long times involved in consideration of climate change impacts. It is clear that application of constant discount rates is not appropriate over long time periods (e.g., intergenerational times) (see, for example, EPA, 2009; Schelling, 1995). There is the suggestion that for consideration of long time periods it may be appropriate to use discount rates that decrease with time (see, for example, Guo, Hepburn, Tol, & Anthoff, 2006). Note that the imposition of any time horizons (as done with traditional measures of global warming potential) to limit consideration of effects after a specific period of time implicitly assumes that the discount rate increases to 100% and that impacts after that time are not counted at all.

Ultimately, O'Hare writes (personal communication, 2012), "at least in the short and medium term, something like compound discounting at a rate in the 3–7% range is necessary to rational decision making about any actions with consequences that occur in the future. This discounting must be applied to something like the social cost and not mere quantities of discharge." Richards (1997) suggested that "at a minimum, carbon discount rates should be tested for values equal to the social discount rate and zero." In 2009, Richards (in EPA, 2009) suggested discount rates of 2%, 3%, and 5%. The specific discount rate chosen depends on the circumstances. Although nearly all individuals possess a time preference, the strength of this preference can vary greatly and with it the corresponding discount rate. In the realm of policy making and finance, the selected discount rate is often simply the market interest rate, which generally fluctuates between 2% and 7%. Considering the long time horizons associated with climate change and climate change policy, small changes to the discount rate can have very large consequences. A widely cited report on the costs and benefits of climate mitigation strategies and published responses that criticize its use of very low discount rates illustrate the large impact of discount rates over long time periods (see Nordhaus, 2007; Stern, 2006).

Note that the decision to ignore time is in effect a decision to assume that the value of emissions is not affected by the time path of emissions and that the appropriate discount rate is 0. Marland et al. (2010), in the context of the carbon stored in durable wood products, showed that where discounting of carbon flows is implemented, it is very important to represent the time path of CO_2 emissions as accurately as possible.

There is much discussion and uncertainty about appropriate rates for compounded discounting, but at the same time there is a widespread consensus that the time value of carbon emissions is important. Specifically, as Richards wrote in 1997, "the time value of carbon is an important issue that requires an explicit decision." Writing in 2009, Richards added "if it doesn't matter when it is done, it doesn't matter whether it is done" (EPA, 2009, p. F-2).

5.2. Discounting Summary

The production and use of biogenic feedstocks for energy can in some circumstances have emission implications extending well into the future. Questions then arise about whether and how to value emissions fluxes that occur over time in present terms. Although there is no single, scientifically correct treatment of time, the choice of treatment may have significant impacts on the results of an accounting framework application. It is important to consider possible treatments of time and the implications of different treatments in terms of the respective strategies chosen for long-term and short-term emission accounting.

The prevailing view in the technical literature is that there is a value of time that can have important ramifications for prospective accounting and analysis, that it ought to be considered explicitly, and that time preference is traditionally viewed as related only to monetary or other values and is not inherent in physical measures of carbon emissions. Aside from certain financial transactions where there is an explicit discount rate (the interest rate), it can be difficult to determine an appropriate discount rate for any given circumstance, including accounting for GHG emissions over time. The debate continues about how to value (i.e., what discount rates to choose) when evaluating the future value of biogenic CO_2 emissions, where the impacts on the global carbon cycle may occur over very long periods of time and the impact of small changes in discount rate can be very large. The scientific literature does not provide guidance on selecting one appropriate discount rate but does suggest using multiple values to illustrate the great importance of time.

The decision on how to treat the time value of biogenic CO_2 emissions (or sequestration) will likely fall to policies or programs like a carbon tax, a cap-and-trade system, or other legal decisions that deal with society's willingness to consider the inherent risks of a changing climate. The decision to not discount the value of emissions over time is an effective decision to select a discount rate of 0. For the purposes of accounting for biogenic CO_2 emissions from stationary sources, the framework application in this report focuses primarily on the physical flows of biogenic CO_2 and, in the forward-looking context, the comparison of different potential flows across alternative future scenarios. Applications of the framework could incorporate discount rates into calculations of the biogenic assessment factor as appropriate for that specific application.

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