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ACCOUNTING FRAMEWORK FOR BIOGENIC CO_2 EMISSIONS FROM STATIONARY SOURCES

Accounting Framework for Biogenic CO_2 Emissions from Stationary Sources

Prepared by the

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Acronyms

ACRES	Acres Needed
AFOLU	Agriculture, Forestry, and Other Land Use
ASTM	American Society for Testing and Materials
AVOIDEMIT	Avoided Emissions
BAF	Biogenic Accounting Factor
BAU	Business-As-Usual
BTU	British thermal unit(s)
C	Carbon
C&D	Construction and Demolition
CCS	Carbon Capture and Storage
CH_4	Methane
CO	Carbon monoxide
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
DDG	Distiller Dried Grains
EPA	U.S. Environmental Protection Agency
FEEDN	Feedstock Needed
FIA	Forest Inventory and Analysis
GHG	Greenhouse gas
GPP	Gross Primary Production
GROW	Growth
GWP	Global warming potential
IPCC	Intergovernmental Panel on Climate Change
LAR	Level of Atmospheric Reduction
LEAK	Leakage
LUCF	Land-Use Change and Forestry
MMS	Manure Management System
MSW	Municipal Solid Waste
N_2O	Nitrous Oxide
NASS	National Agricultural Statistics Service
NBE	Net Biogenic Emissions
PGE	Potential Gross Emissions
PNW	Pacific Northwest
PRODC	Carbon in Products
SEQP	Sequestered Fraction
SITE_TNC	Total Net Change in Site Emissions
$SITE\_TNC_{acre}$	Total Net Change in Site Emissions per Acre
SITEEMIT	Changes in Net Site Emissions

SITESEQ	Changes in Net Site Sequestration
tCO_2e	Metric Tons of Carbon Dioxide Equivalent
TDW	Tire-Derived Waste
TFP	Tons of Feedstock Produced
Tg	Teragrams
UNFCCC	United Nations Framework Convention on Climate Change
USDA	United States Department of Agriculture
USFS	United States Forest Service
YIELD_ACRE	Yield per Acre

Executive Summary

ACCOUNTING FRAMEWORK FOR BIOGENIC CO_2 EMISSIONS FROM STATIONARY SOURCES

The purpose of this report is to consider the scientific and technical issues associated with accounting for emissions of biogenic carbon dioxide (CO_2) from stationary sources, and to develop a framework to account for those emissions. In this report, biogenic CO_2 emissions are defined as CO_2 emissions directly resulting from the combustion, decomposition, or processing of biologically based materials other than fossil fuels, peat, and mineral sources of carbon through combustion, digestion, fermentation, or decomposition processes. Biogenic CO_2 is emitted from stationary sources through a variety of energy-related and industrial processes.

This report and accounting framework were developed for the policy context where it has been determined that a stationary source emitting biogenic CO_2 requires a means for "adjusting" its total onsite biogenic emissions estimate on the basis of information about growth of the feedstock and/or avoidance of biogenic emissions and more generally the carbon cycle. The decision on whether to adjust biogenic CO_2 emissions from a stationary source in any particular program is a policy decision, and this study does not provide any recommendations or judgments about that issue. Rather, this report provides a general accounting framework that could be used as a means to adjust biogenic CO_2 emissions at stationary sources.

As discussed in Section 2, fossil and biogenic carbon interact with the overall carbon cycle on very different time scales, and this difference has implications for understanding estimates of biogenic CO_2 emissions from stationary sources. CO_2 emissions from the consumption of fossil fuels will inevitably increase the amount of carbon in the atmosphere on policy-relevant time scales, but such an outcome is not inevitable with the consumption of biologically based feedstocks. The amount of biologically based feedstocks consumed at stationary sources during a year may be partially or completely balanced by the amount of feedstock that grows during the year. On that basis, as discussed in Section 2, EPA concludes that in order to develop an accounting framework to adjust total onsite biogenic emissions at a stationary source, it is essential to assess the carbon stored by growth of biologically based feedstocks. Consistent with this conclusion, the Intergovernmental Panel on Climate Change (IPCC) notes the importance of looking at the status of carbon fluxes on land in order to understand the CO_2 impacts of bioenergy:

> *If energy use, or any other factor, is causing a long term decline in the total carbon embodied in standing biomass (e.g., forests), this net release of carbon should be evident in the calculation of* CO_2 *emissions described in the Land-Use Change and Forestry chapter.*[1]

The balance of this report addresses the development of a framework that can be applied from the perspective of a stationary source that is adjusting its total onsite biogenic emissions, and reflects the connection between onsite biogenic CO_2 emissions and the land base providing the biologically based feedstock. The report and the framework are narrower in scope and are not intended to address the different issues that arise when considering biogenic CO_2 emissions outside of this specific context, such as issues that arise when comparing lifecycle emissions between biogenic and fossil fuels. In order to develop an approach that could be relatively easily adopted and understood, EPA designed the framework to meet certain criteria. Therefore, the framework:

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[1] Page 1.10. Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories: Reference Manual

- Accurately reflects the carbon outcome.
- Is scientifically rigorous/defensible.
- Is simple and easy to understand.
- Is simple and easy to implement.
- Is easily updated with new data.
- Uses existing data sources.

Section 3 identifies the important technical and methodological issues that should be considered when constructing any framework for developing an adjustment factor for biogenic CO_2 emissions at stationary sources that reflects changes in carbon stocks occurring beyond the stationary source. Decisions on these factors are critical in development of the framework, and may differ in application depending on program and policy requirements and objectives. Section 3 presents an overarching discussion of these issues, along with the implications of specific decisions about the issues, which are summarized here.

- The starting point for the framework is to identify which greenhouse gases (GHGs) to include: i.e., only biogenic CO_2 or other GHGs as well. The next step is to consider the quantity of onsite biogenic emissions from the stationary source, also called "direct emissions" of biogenic CO_2. Determining the boundary for offsite factors that are included in the framework is another critical step. Offsite factors include the gains and losses of biologically based carbon occurring through: (1) growth of the feedstock, (2) other CO_2 emissions and sequestration on land, and (3) land-use change. For any land included in the scope, carbon stocks could change across any of the five terrestrial carbon pools, particularly in above-ground biomass and soils. Altogether, these carbon stock changes and their corresponding effect on the net CO_2 contribution are at the core of the offsite assessment. Spatial and temporal scales are also critical factors with interrelated effects. An annual emissions estimation or measurement is a typical temporal scale. When considering an appropriate spatial scale for an accounting framework there are important implications related to measurement, precision of estimates, and cross-boundary exchanges, which can have significant influence on framework application outcomes. The balance between emissions and sequestration is an important factor in assessing the biogenic CO_2 emissions from stationary sources, and an accounting framework needs to have the appropriate temporal and spatial scales to properly assess that balance.

- A "baseline" against which to compare the impact of biogenic feedstock production and utilization is another critical component of an accounting framework for adjusting biogenic CO_2 emissions at stationary source. The determination of what baseline to use can make a significant difference in results and will likely depend on the specific context(s) in which the accounting framework is applied. Baselines related to biogenic CO_2 emissions have been defined in at least three ways, focusing on: (1) the net change from a current reference point, (2) the net change from a bounded business-as-usual future, and (3) the net change from an alternative future. The fundamental difference among these approaches relates to the question being asked. The first approach asks, "Is there more or less carbon stored in the system (the stationary source and its feedstock-supply source) at the end of an assessment period than there was at the beginning?" The second one asks, "Is more or less carbon stored after the assessment period in the system (the stationary source and its feedstock-supply source) *than we expected*?" The third one asks, "How do net emissions to the atmosphere, including the stationary source using biologically based feedstocks, differ from emissions that would have been expected if that stationary source was not in place or used other fuel feedstocks?" Again, the decision to use any of these approaches in an accounting framework may rest on the kind of analysis that is involved. Furthermore, when developing a baseline there are other important issues to consider that depend largely on application of a framework to a specific program and policy. These include, but are not limited to, exogenous effects on land-based carbon stocks, fuel treatments, and marginal versus average impact accounting.

- There are a wide variety of feedstocks that result in biogenic CO_2 emissions from stationary sources. These feedstocks differ in physical properties, origin, life cycle, and whether they are deliberately raised as an energy feedstock, are reclaimed wastes from other processes, or are salvaged following extreme events such as hurricanes or insect outbreaks. It may be appropriate for the accounting framework to distinguish among the feedstock types or production systems. For example, annual crops might be accounted for differently than perennial crops, and both might be accounted for differently than wastes (e.g., due to their characteristics annual crops and waste materials may result in more of an adjustment at the stationary source than other feedstocks). Further, a feedstock in continuous supply may be accounted for differently than a feedstock available only occasionally as the result of fire or insect infestation. There are three broad categories of feedstocks that largely capture all of the sources for biologically based materials that might be used in a stationary source: (1) Forest-Derived Woody Biomass, (2) Agricultural Biomass, and (3) Waste Materials.

Section 4 describes EPA's accounting framework for biogenic CO_2 emissions from stationary sources, including explanation for any decisions EPA made about the methodological issues detailed in Section 3. The following table summarizes these decisions:

Methodological Issue	**Description**	**Status in EPA Framework**
Gases	GHG emissions related to biologically based feedstocks and their use (e.g., CO_2, CH_4, N_2O).	Framework includes biogenic CO_2.
Direct Emissions	Direct emissions that result from use of biologically based feedstock at the stationary source.	Included.
Feedstock Losses During Transportation and Storage	Biologically based feedstock for use at a stationary source may be lost during transport from the production site and/or may decompose during storage before use.	Included.
Carbon Contained in Products and Byproducts	Some of the biologically based feedstock arriving at the source may be transformed into long-term products, post-combustion products, or fuels that contain carbon and exit the stationary source other than out the stack.	Included. Framework accounts separately for carbon storage in products and post-combustion byproducts.

Methodological Issue	Description	Status in EPA Framework
Feedstock Growth	Emissions and sequestration on the land (all five terrestrial carbon pools) supplying the biologically based feedstocks.	Included.
Direct Land-Use and Management Changes	Emissions/sequestration related to direct landuse or management is changed to produce a biologically based feedstock for energy use.	Included.
Indirect Land-Use Change and Leakage	Leakage occurs when new biologically based feedstock use (demand) alters the amount of feedstock-related commodities entering markets for other uses (supply), thus influencing market prices and inducing production alterations elsewhere offsite, including possible land-use change and related emissions/sequestration.	No specific quantification methodology for leakage or indirect land-use change included in the framework. However, the framework does include a term that can be used to accommodate this consideration.
Temporal Scale	Basic boundary for assessing emissions to the atmosphere, including annual or multi-year.	Framework applies an annual or annualized time step for all terms when such data are available. Where annual data are not available, the approach will vary depending primarily on the dataset available for the feedstock involved.
Spatial Scale	Level, land-base, and boundary at which emissions and sequestration of biologically based feedstocks are assessed, including international, national, regional, or local.	Framework uses a regional scale.
Baselines	A means to compare the impact of biogenic feedstock production and utilization. The determination of what baseline to use can make a significant difference in results and will likely depend on the specific context(s) in which the accounting framework is applied. There are three main types of baselines: (1) the net change from a current reference point, (2) the net change from a bounded business-as-usual future, and (3) the net change from an alternative future.	Framework uses a reference point baseline.

Methodological Issue	**Description**	**Status in EPA Framework**
Feedstock Categorization and Disaggregation	Categories of biologically based material that group feedstocks based on similarities in physical properties, origin, life cycle, etc.	Framework uses three main categories of feedstocks: (1) forest-derived woody biomass, (2) agricultural biomass, and (3) waste materials.

Section 5 presents the framework as a series of equations, along with definitions and key considerations. The end result of the equation is the "biogenic accounting factor" or BAF, which can be applied as an adjustment to stationary source emission estimates in order to reflect the connection with the land. The value for BAF typically falls between 0 and 1, with the possibility of being negative in certain circumstances. A value of 0 would mean that the biogenic CO_2 emissions are balanced by offsite factors related to the carbon cycle, such as feedstock growth (e.g., an annual crop with no land-use or land management change emissions). A value of 1 would mean that 100 percent of the biogenic CO_2 emissions are contributed to the atmosphere; in other words, the offsite factors related to the carbon cycle did not offset any of the direct biogenic CO_2e emissions from the stationary source. An intermediate value between 0 and 1, such as 0.2 or 0.5 would mean that only a portion of the biogenic CO_2 emissions could be adjusted at the stationary source; in this case, the offsite factors related to the carbon cycle offset 80 percent or 50 percent of the biogenic CO_2 emissions at the stationary source. In some situations, a negative value (e.g., −0.2) could result, indicating that the offsite factors related to the carbon cycle would offset 20 percent more than the total of biogenic CO_2 emissions. Such a situation could result, for example, if biogenic feedstock growth sequesters CO_2 at the feedstock production site with very little or no land-use change, coupled with a substantial amount of CO_2 that remains after use for bioenergy, sequestered in ash, biochar, or carbon capture and storage (CCS) processes.

Section 6 is the conclusion. It reiterates that the framework provides the critical link from the direct emissions at the stationary source to the offsite factors related to the carbon cycle in a scientifically and technically rigorous manner. It also acknowledges that as the framework is adapted for implementation in a particular program or policy, it may also require a recognition and accommodation of complementary policies relevant to biogenic CO_2 emissions, such as policies that may be geared towards landowners rather than stationary sources (e.g., feedstock certification), or utilization of biomass in an energy-efficient manner.

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Figure 2-1: The global carbon cycle. Annual carbon fluxes for the 1990s are shown in gigatons of carbon (GtC/yr). Black fluxes denote natural carbon flows, while anthropogenic contributions are shown in red. GPP refers to gross primary production, or the rate at which photosynthetic organisms capture chemical energy in their biomass (IPCC, 2007a, Figure 7.3, p. 515). 4

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1 Introduction

1.1 Purpose

The purpose of this report is to consider the scientific and technical issues associated with accounting for emissions of biogenic carbon dioxide (CO_2) from stationary sources,[2] and to develop a framework to account for those emissions. In this report, biogenic CO_2 emissions are defined as CO_2 emissions directly resulting from the combustion, decomposition, or processing of biologically based materials other than fossil fuels, peat, and mineral sources of carbon through combustion, digestion, fermentation, or decomposition processes.[3]

This report and accounting framework were developed for the policy context where it has been determined that a stationary source emitting biogenic CO_2 requires a means for "adjusting" its total onsite biogenic emissions estimate on the basis of information about growth of the feedstock and/or avoidance of biogenic emissions and more generally the carbon cycle. The decision on whether to adjust biogenic CO_2 emissions from a stationary source in any particular program is a policy decision: this study does not provide any recommendations or judgments about that issue. Rather, this report provides a general accounting framework that could be used as a means to adjust biogenic CO_2 emissions from stationary sources in a scientifically and technically rigorous manner.

The development of an adjustment for a stationary source's onsite biogenic CO_2 emissions is based on the fact that a fundamental difference exists between fossil and biogenic CO_2, which is not reflected in onsite emission totals. Specifically, CO_2 emissions from the consumption of fossil fuels will inevitably increase the amount of carbon in the atmosphere on policy-relevant time scales,[4] but such an outcome is not inevitable with the consumption of biologically based feedstocks. The amount of biologically based feedstocks consumed at stationary sources during a year may be partially or completely balanced by the amount of feedstock that grows during the year. Without a corresponding assessment of the change in the amount of carbon stored by growth, onsite estimates of biogenic CO_2 emissions will not accurately reflect their net impact on the atmosphere.

In order to develop a framework for such an adjustment, the first step is to determine the scope of the analysis. The diagram below shows that, depending on the program and policy requirements and objectives, the scope of a biogenic CO_2 emissions analysis can be quite broad.

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[2] For the purpose of this study, a stationary source is any physical property, plant, building, facility, structure, or installation that emits or may emit greenhouse gases.

[3] Biologically based feedstocks are non-fossilized and biodegradable organic material originating from modern or contemporarily grown plants, animals, or microorganisms (including products, byproducts, residues, and wastes from agriculture, forestry, and related industries, as well as the non-fossilized and biodegradable organic fractions of industrial and municipal wastes, including gases and liquids recovered from the decomposition of non-fossilized and biodegradable organic material). It does not include materials such as peat, coal, petroleum, natural gas, and products that are ultimately derived from biologic materials but are not renewable on policy-relevant time frames.

[4] For the purpose of this study, the policy-relevant time scale is the timeframe of concern required for stabilization of atmospheric GHG concentrations to avoid "dangerous anthropogenic interference with the climate system" (UNFCCC, 1994) http://unfccc.int/essential_background/convention/background/items/1353.php. Parties to the UNFCCC, including the United States, have agreed to use 100 years as the time horizon for calculations of global warming potential (GWP) (IPCC, 2007c) http://ipcc.ch/publications_and_data/ar4/wg1/en/ch2s2-10.html.

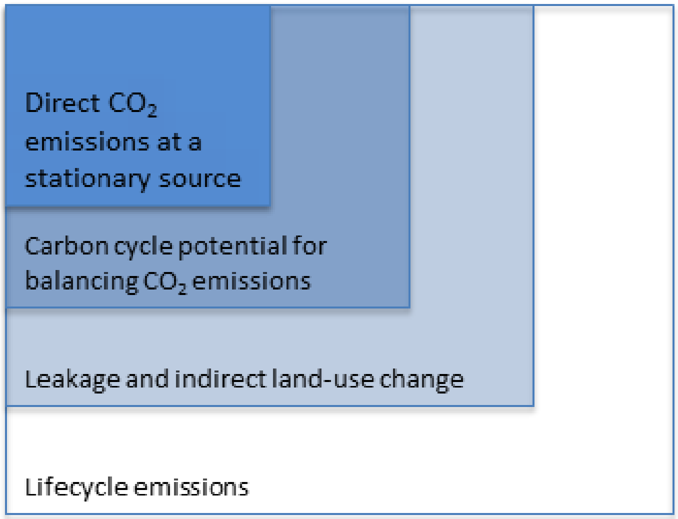

Figure 1-1: Elements of scope for an accounting framework that links onsite biogenic CO_2 emissions with offsite characteristics. The widest possible scope would include all of these nested components. Depending on program context, different elements might be included in an accounting framework for biogenic CO_2 emissions.

The accounting framework in this report does not use the broadest scope possible, as it simply strives to provide a means to adjust a stationary source's total onsite biogenic emissions based on information about the carbon cycle that can be tailored for use in stationary source programs. It is not intended to address the different issues that arise when considering biogenic CO_2 emissions outside of this specific context, such as issues that arise when comparing lifecycle emissions between biogenic and fossil fuels.

In developing the framework for this report, EPA looked at a variety of factors (e.g., which GHGs to include, spatial and temporal scale) beyond the onsite biogenic emissions in order to reflect some of the carbon cycle dynamics described above. While estimating the amount of CO_2 physically emitted from stationary sources is a straightforward task, [5] there are different ways to approach the other factors necessary for a technically and scientifically rigorous analysis. The first part of this report describes the factors and the implications of different decisions about those factors. The second part of the report presents a framework that represents EPA's decisions on those factors based on the context posed above (i.e., one in which a stationary source needs a means for adjusting its total onsite biogenic emissions).

Specifically, this accounting framework is based on the concept of accounting for emissions using a "biogenic accounting factor" (BAF). The BAF can be used to reflect changes in carbon stocks that occur offsite, beyond the stationary source. Use of the BAF may allow for a more accurate assessment than "gross emissions" or default "carbon neutrality" of biogenic CO_2 emissions from stationary sources, because it acknowledges the carbon cycle. The BAF-adjusted emissions from biologically based material from stationary sources (e.g., biomass burning) may be less than gross emissions and they may be greater than zero (See Sections 4 and 5 for more details). The BAF is to be applied to the total biogenic CO_2 emissions from a stationary source.

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[5] The U.S. Environmental Protection Agency (EPA), the Intergovernmental Panel on Climate Change (IPCC) and other organizations have developed peer-reviewed methodologies that can be used for this purpose (EPA, 2009a; IPCC, 1996; WRI/WBCSD, 2011).

1.2 Evaluation Criteria for Framework

This report provides a general framework for developing a BAF that reflects changes in carbon stocks that may occur offsite when biogenic feedstocks[6] are used in stationary sources. In order to develop an approach that could be relatively easily adopted and understood, the framework is designed to meet certain criteria:

- Accurately reflects the carbon outcome.
- Is scientifically rigorous/defensible.
- Is simple and easy to understand.
- Is simple and easy to implement.
- Is easily updated with new data.
- Uses existing data sources.

1.3 Organization of this Report

This report contains five sections. **Section 1** is this Introduction. **Section 2** describes the scientific basis for accounting for biogenic CO_2 emissions from stationary sources, including the distinction between fossil and more recent biologically based CO_2. This section also evaluates existing accounting approaches for biogenic CO_2 emissions from stationary sources and determines that there is a need for a different accounting framework to adjust a stationary source's total onsite biogenic emissions based on information about the carbon cycle. **Section 3** describes the technical and methodological issues (e.g., GHGs to include, spatial and temporal scale) related to biogenic CO_2 emissions from stationary sources that should be considered when developing a framework to provide an onsite biogenic emissions' adjustment. Then, **Section 4** and **Section 5** describe and present EPA's accounting framework for biogenic CO_2 emissions from stationary sources, including explanations for the decisions EPA made about the methodological issues detailed in Section 3. **Section 6** is the Conclusion. Finally, the appendix presents case studies to demonstrate how the accounting framework could work in practice, and to highlight the differences between certain policy decisions.

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[6] Biogenic feedstocks are defined as biologically based materials that are used for combustion, product processes, or otherwise decompose at a stationary source.

2 Scientific Issues and Existing Approaches

Section 2 describes the scientific and technical foundation for accounting for biogenic CO_2 emissions from stationary sources, including the distinction between fossil and more recent biologically based CO_2. This section also evaluates existing accounting approaches for biogenic CO_2 emissions from stationary sources and determines that there is a need for an accounting framework to adjust a stationary source's total onsite biogenic emissions based on information about the carbon cycle.

2.1 Scientific Background

A. The Carbon Cycle

Carbon is ubiquitous in the Earth system and is in continuous and rapid circulation among carbon reservoirs on land, in the ocean, and in the atmosphere. As shown in Figure 2-1, there are many processes that drive carbon flows among the various reservoirs. Collectively, these flows are referred to as the global carbon cycle.

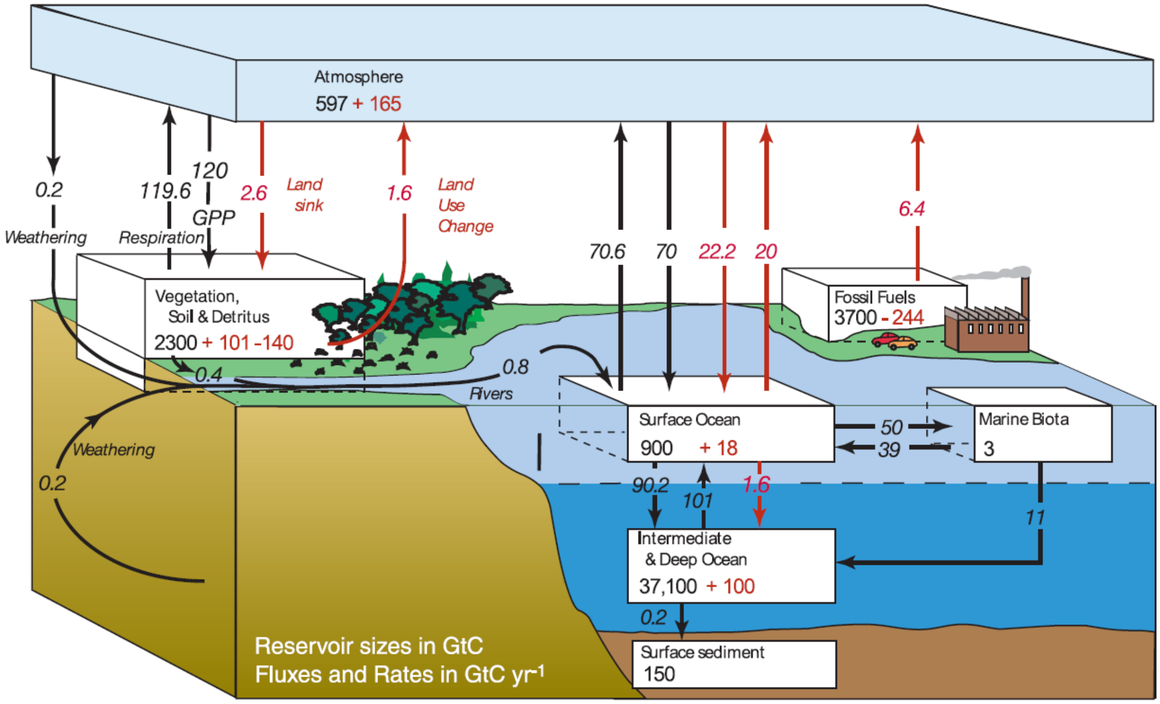

Figure 2-1: The global carbon cycle. Annual carbon fluxes for the 1990s are shown in gigatons of carbon (GtC/yr). Black fluxes denote natural carbon flows, while anthropogenic contributions are shown in red. GPP refers to gross primary production, or the rate at which photosynthetic organisms capture chemical energy in their biomass (IPCC, 2007a, Figure 7.3, p. 515).

Carbon resides in the atmosphere mostly as CO_2, but also as methane (CH_4), carbon monoxide (CO), and a variety of minor compounds. Through photosynthesis, plants take up carbon from the atmosphere to produce wood, sugars, carbohydrates, and other plant products that are, in turn, consumed by animals for food, shelter, and energy (IPCC, 2007c; King et al., 2007). Carbon is returned to the atmosphere through respiration by plants and animals (including humans); by industrial processes, including combustion; by wildfires; or by decomposition. Carbon that is not returned to the atmosphere is stored on land, in soils, or in sediments in fresh water or marine environments (IPCC, 2007c; King et al., 2007). Carbon is also exchanged between the atmosphere and the oceans, where it resides as a variety of dissolved inorganic and organic species. Ocean currents and biologic activity circulate carbon from the surface into deep ocean reservoirs and back (IPCC, 2007c; King et al., 2007). Phytoplankton take in carbon that is dissolved in the oceans. When these small plants die, a portion of the carbon stored in them is drawn deeper into the ocean (a process referred to as "biological pumping") (IPCC, 2007c; King et al., 2007). Over the much longer term, carbon is removed from the atmosphere through reactions involved in the weathering of silicate rocks (IPCC, 2007c).

There are five terrestrial carbon pools—(1) aboveground and (2) belowground biomass,[7] (3) dead wood, (4) litter, and (5) soil carbon—and carbon is transferred between the atmosphere and these pools through different processes. Biological material takes atmospheric CO_2 and stores the carbon in the form of cellulose and other carbon-based compounds. In early stages of growth, trees and other plants may store carbon rapidly. As growth slows, so does the rate of carbon sequestration.[8] Trees and plants naturally release carbon throughout their life cycle as they respire and shed leaves, branches, fruit, and other materials that decompose in the environment. Carbon is also released when trees and other biomass are cleared and burned (EPA, 2010d). Soils serve as not only a source of GHG emissions to the atmosphere, but also a reservoir to store carbon removed from the atmosphere by plants (Paustian et al., 1997). The magnitude of these emissions and sinks in soils is a function of underlying biogeochemical processes, which are influenced by climate, soil type, land use,[9] and land management (Ogle et al., 2005; Smith, P. et al., 2007). Soil organic carbon is the dominant organic pool for long-term carbon storage in cropland and grassland ecosystems, because in these systems herbaceous biomass and litter pools are ephemeral with effectively no potential for longer-term increases or decreases in carbon storage (IPCC, 2006b). Soil organic carbon is also a significant component of the carbon budget in forestlands, but the influence of land use and management in forests on soil carbon are less well understood (IPCC, 2006b).

Land-use and land-use change, which are inherently anthropogenic[10] activities, can cause measurable changes in all five terrestrial pools as a result of changes in biomass inputs and/or removals (IPCC, 2000, 2006b). In the event of land-use change, carbon stocks will, in time, reach a new steady-state level, either higher or lower than the initial level, depending on the net effect of these changes on the various carbon pools (IPCC, 2000). The transition to a new steady-state level of carbon stocks in the carbon pools following a land-use or management change will have a net impact on atmospheric concentrations of CO_2. If carbon stocks are higher when summed across the carbon pools, then the land area has removed CO_2 from the atmosphere. If the carbon stocks are lower overall, then the land area has added CO_2 to the atmosphere.

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[7] Biomass is defined as organic material both above-ground and below-ground, and both living and dead, e.g., trees, crops, grasses, tree litter, roots, etc. Biomass literally means living matter, but the term is also used for any organic material derived from plant and animal tissue. In the context of bioenergy, biomass is any material of biological origin excluding material embedded in geological formations and transformed to fossil.

[8] Sequestration is the addition of a substance of concern to a reservoir. The uptake of carbon-containing substances, in particular carbon dioxide, is often called (carbon) sequestration.

[9] Land use refers to the total of arrangements, activities, and inputs undertaken in a certain land cover type (a set of human actions). The term "land use" is also used in the sense of the social and economic purposes for which land is managed (e.g., grazing, timber extraction, and conservation).

[10] Anthropogenic is defined as resulting from or produced by human beings.

Carbon in fossil fuel reservoirs, such as coal seams and oil and gas deposits, was removed from the atmosphere by plants over millions of years, but was not returned to the atmosphere through respiration, wildfires, or decomposition. Instead, because of geologic processes, the carbon that accumulated in these deposits has been isolated from the atmosphere and the active carbon cycle. Without human intervention, fossil-fuel carbon could remain isolated from the active carbon cycle long into the future.

Carbon is also stored in peat, which forms when plant material, usually in marshy areas, is inhibited from decaying fully by acidic and anaerobic conditions. Today's peatlands have formed over thousands of years, and the carbon in them has also has remained largely isolated from the active carbon cycle since their formation. Under the proper conditions, peat is the earliest stage in the formation of coal. Peat is generally categorized with the fossil fuels, because it is involved in cycles with longer time scales than living plants and is not renewable on policy-relevant time scales.

Anthropogenic extraction and oxidation of the carbon in fossil-fuel reservoirs and peatlands return this "older" historical carbon to the atmosphere and the active carbon cycle. Collectively, the consumption of fossil fuels and peat, along with the decrease in the amount of carbon stored in vegetation, have led to an increase in CO_2 concentration in the atmosphere over the last 200 years (Le Quéré et al., 2009).

The global biogeochemical cycling of carbon involves wide differences in time scales. Carbon that is respired by plants and animals, transported by rivers, dissolved by ocean surface waters, and mixed by ocean currents, cycles on the scale of decades to years or less. For example, over the course of a year, carbon can be removed from the atmosphere by a growing corn stalk, cut during corn harvest, and returned to the atmosphere via combustion or decomposition. Within the course of a century, carbon can be removed from the atmosphere by a growing tree and released back to the atmosphere when the tree is burned or otherwise decomposed. Carbon is also vented by volcanoes, released from rocks by erosion, and deposited as sediments in marine and terrestrial basins in processes that cycle carbon on geologic time scales (see IPCC, 2007c; King et al., 2007).

Of particular importance to this report is the need to distinguish between modern biological materials, which circulate carbon on policy-relevant timeframes, and materials like fossil fuels or peat that circulate carbon on much longer geologic timescales (Figure 2.2). In general, the time scale chosen for a particular issue or analysis is a policy or economic decision. In the case of climate change, the choice of an appropriate policy-relevant time scale is also linked to views about the time horizon over which dangerous interference in the climate system might occur. More specifically, biogenic CO_2 emissions from stationary sources will not inevitably increase the amount of CO_2 in the atmosphere on policy-relevant time scales, unlike CO_2 emissions from combustion of fossil fuels.

For example, it is possible to harvest and consume biomass such that, when averaged over a year's growing cycle, the amount harvested and burned in a year is exactly balanced by the amount that grows during the year. In this theoretical case, the mass of carbon in the biosphere (i.e., in the living organisms on Earth) will be the same at the end of the year as it was at the beginning, and the net impact on the atmosphere should be zero, averaged over a year. Of course, if the harvested biologically based feedstock is not replaced by growth, or if the process of harvesting involves release of non-biogenic emissions that are not offset, then there will be a net increase in the amount of CO_2 in the atmosphere. Similarly, if more biogenic material is grown than is harvested and used, or is emitted by other processes such as natural disturbance, then on average the biosphere is acting as a net sink for CO_2. According to the *Inventory of U.S. Greenhouse Gas Emissions and Sinks* (EPA, 2011a), approximately 1,015 Tg CO_2 (million metric tons CO_2e), or 15 percent of the total emission of 6,633 Tg CO_2e, are absorbed by sinks in the U.S. Land Use and Land-Use Change Sector (e.g., forests, mineral soils, urban trees).

In this report, the focus is on those carbon fluxes[11] that are in the upper left quadrant of Figure 2.2: these are emissions that are both anthropogenic and cycle on policy-relevant timescales. The characterization of particular fluxes as either natural or anthropogenic is ultimately a matter of defining a boundary within a spectrum of fluxes. The Intergovernmental Panel on Climate Change (IPCC) defines fluxes as being natural or anthropogenic based on what originally caused the flux to occur (IPCC, 2006b): if the flux is the result of a human activity, then it is categorized as anthropogenic, but if the flux is caused by something beyond human control, then it is categorized as natural. This distinction between natural and anthropogenic fluxes is a matter of convention and is important in terms of understanding the impact of human intervention in the global carbon cycle. However, it is not relevant for quantifying the effect of emissions on the atmosphere, since all emissions contribute to the radiative balance of the atmosphere.[12] In fact, other than the differences in the isotope ratios of ^{14}C to ^{12}C or ^{13}C to ^{12}C, the physical attributes of CO_2 released from processing, combustion, or decomposition of biogenic material are the same as those of CO_2 released from any other process, including burning fossil fuels. In other words, no matter what the original source of the CO_2, the behavior of the molecules in the atmosphere in terms of radiative forcing, chemical reactivity, and residence time in the atmosphere is effectively the same.

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[11] Carbon flux is defined as transfer of carbon from one carbon pool to another in units of measurement of mass per unit of area and time.

[12] Radiative forcing is a function of the total concentration of CO_2 in the atmosphere, without a need to differentiate whether the CO_2's origin was biogenic or fossil-based. Radiative forcing is the change in the net, downward minus upward, irradiance (expressed in W/m^2) at the tropopause due to a change in an external driver of climate change, such as, for example, a change in the concentration of CO_2 or the output of the Sun.

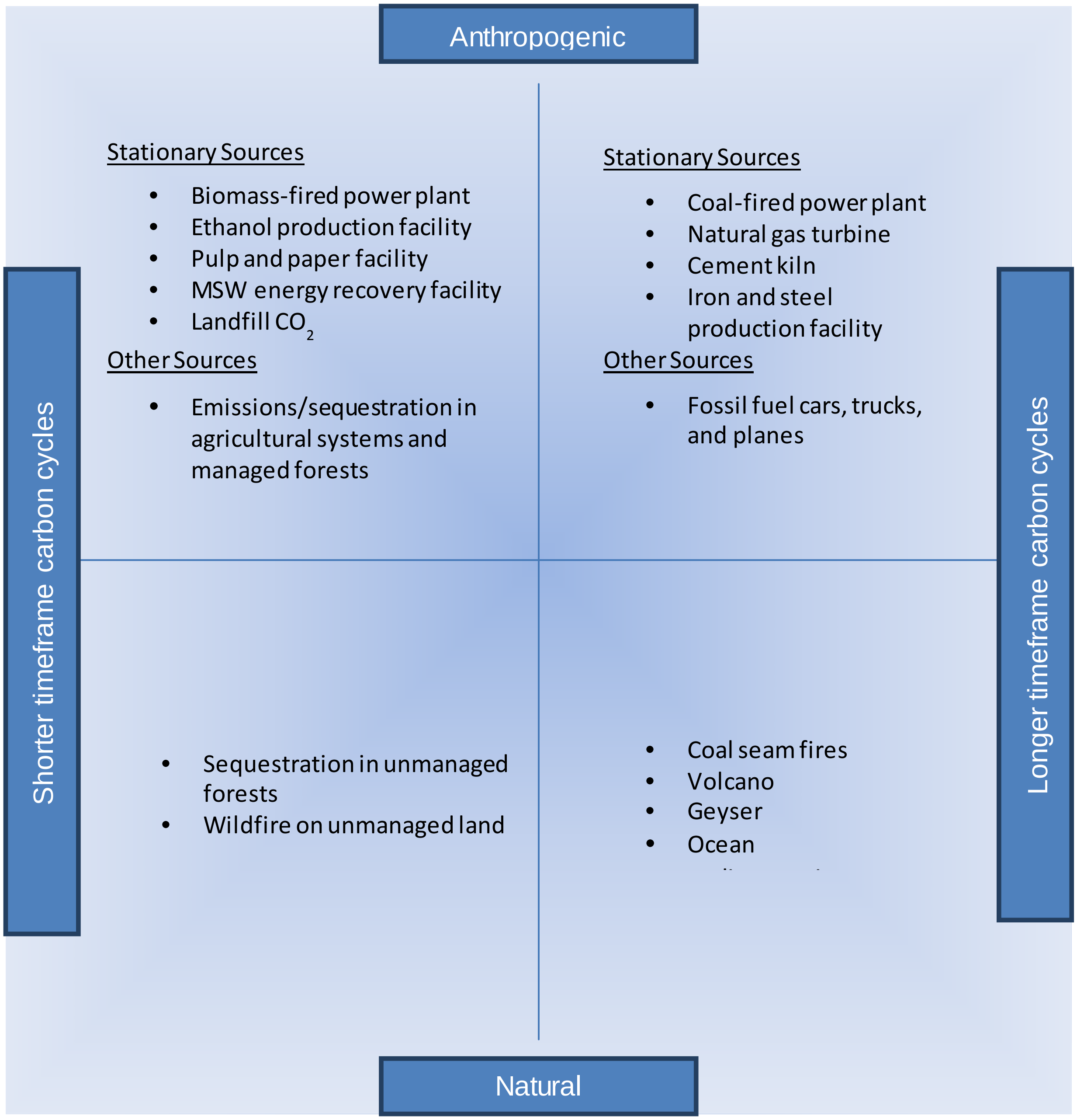

Figure 2-2: Carbon fluxes with the atmosphere can be defined in terms of fossil/biogenic and natural/anthropogenic origin.

B. Non-CO_2 Greenhouse Gases

Although the GHGs CO_2, CH_4, and N_2O occur naturally in the atmosphere, human activities have increased their atmospheric concentrations. From the pre-industrial era to 2005, concentrations of these GHGs have increased globally by 36, 148, and 18 percent, respectively (IPCC, 2007c). Recent trends in emissions of these gases in the United States can be seen in Figure 2-3. Some reports also estimate small natural sinks for CH_4 and N_2O.[13]

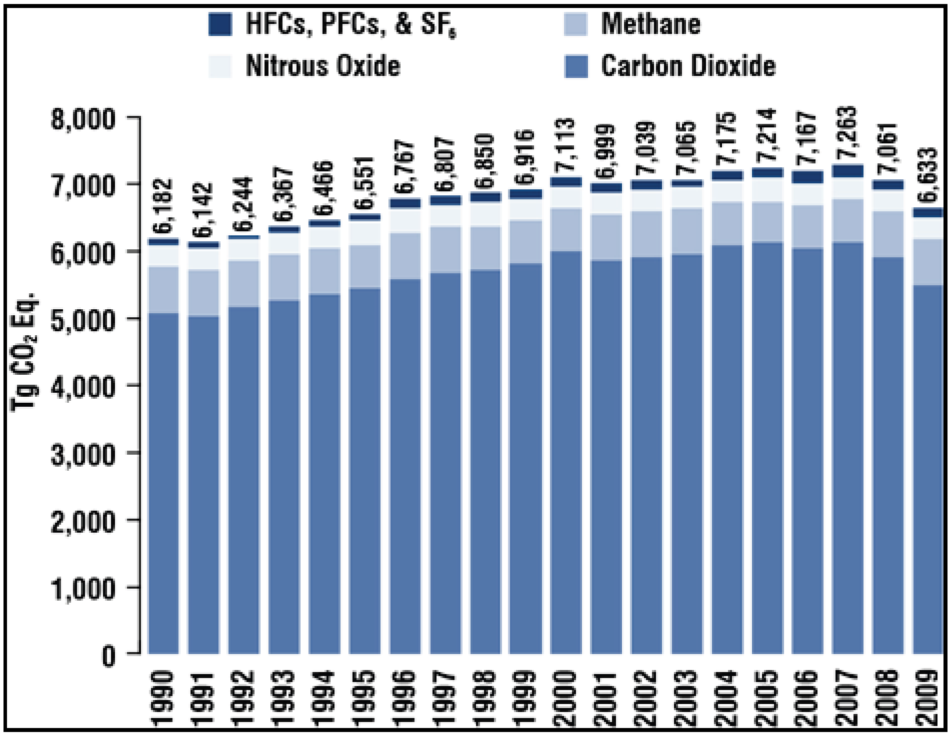

Figure 2-3: The overall trends in total U.S. greenhouse gas emissions by gas (in Tg CO_2e) since 1990 (Source: EPA, 2011a).

All of these GHGs (CO_2, CH_4, and N_2O) are considered to be chemically long-lived in the atmosphere; unlike the other GHGs, however, CO_2 is not readily converted by chemical, photolytic, or other reaction mechanisms, allowing the carbon in CO_2 to cycle between different reservoirs in the atmosphere, ocean, land vegetation, soils, and sediments. CH_4 and N_2O also have processes by which they are removed from the atmosphere and, as with CO_2, their concentrations in the atmosphere are a result of the balance between processes of emission and removal.[14] However, CH_4 and N_2O are removed from the atmosphere by chemical and physical processes over which humans

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[13] Some data and reports, such as EPA's *Methane and Nitrous Oxide Emission from Natural Sources* (2010a), do reflect small sinks of methane. Natural sinks for N_2O include soils (e.g., wetlands), where under certain conditions (oxygen levels, nitrogen levels, pH, and temperature) de-nitrification can consume N_2O.

[14] While IPCC (2007c) does provide global CH_4 emissions from all sources, it also states that "source stabilization" has occurred to the point where total emissions from both anthropogenic and natural sources roughly equal the total CH_4 sinks, making the growth rate in atmospheric CH_4 close to zero. One study presented in IPCC (Mikaloff Fletcher et al., 2004a, 2004b) shows natural sources at 260 Tg/year, anthropogenic sources at 350 Tg/year, and sinks at 577 Tg/year (compared with 610 Tg/year total emissions). IPCC pegs the average values at 582 Tg/year total emissions versus 581 Tg/year total sinks. For the key CH_4 cycle sections in IPCC, see http://www.ipcc.ch/publications_and_data/ar4/wg1/en/ch7s7-4-1.html and http://www.ipcc.ch/publications_and_data/ar4/wg1/en/ch2s2-3-2.html.

have little direct interaction (EPA, 2010a). CH_4 is also part of this active global cycling of carbon but, since it does not contain carbon, N_2O is not (IPCC, 2007c).[15]

CO_2 is a long-lived and inevitable product from the combustion of both biomass and fossil fuels; it also can be removed from the atmosphere by systems (e.g., forests, soils, carbon capture and storage) that can be anthropogenically managed. Ultimately, it is this potential to balance emissions to the atmosphere with removals from the atmosphere through the active carbon cycle, and the magnitude of those fluxes, that makes CO_2, including biogenic CO_2 emissions, unique compared with other GHGs.

Typically, unless conditions are anaerobic, the consumption of biologically based material at stationary sources does not produce significant quantities of non-CO_2 emissions. Under conventional biomass combustion conditions (i.e., at combustion temperatures greater than approximately 2,200°F), CH_4 and N_2O emission rates are orders of magnitude lower than CO_2 (IPCC, 2006a). However, CH_4 and N_2O emissions from combustion are not proportional to carbon content, as is the case with CO_2 (EPA, 2011c). Methane emissions are influenced primarily by the CH_4 content of the fuel, combustion efficiency, and flue gas turbulence. N_2O emissions are closely related to combustion temperature, and the combustion temperature is driven by the excess air ratio and the fuel's moisture content (Van Loo and Koppejan, 2008). It should be noted that combustion of nitrogenous feedstocks yields precursors that can form N_2O in the flue gas. In non-conventional combustors (i.e., fluidized bed combustors) or in conventional combustors burning predominantly high moisture fuels (e.g., stoker boilers with high air-to-fuel ratios burning fuels with greater than 40 percent moisture), normal operating temperatures can be within the range that favors formation of N_2O. For a fuel with 1 percent nitrogen content, and assuming 2 percent of the nitrogen was converted to N_2O, the atmospheric forcing attributable to the nitrogen content of biomass is estimated to be approximately 10 percent of the total global warming potential (GWP) associated with biomass combustion.

Biologically based material may be intentionally or unintentionally managed anaerobically at stationary sources. Under these conditions, a stationary source may emit a significant amount of carbon in the form of CH_4 rather than CO_2. For example, waste materials, such as municipal solid waste, can be sent to landfills where they decompose over many decades (EPA, 2011b; IPCC, 2006c). Landfill gas is approximately 50 percent CH_4 and 50 percent CO_2 by volume, and because CH_4 is a potent GHG with a 100 year GWP of 21, the overall impact on the atmosphere will be far greater than if the biological material is combusted or decomposes aerobically and produces primarily CO_2. As a result, while combustion may add CO_2 to the atmosphere, it may also have the benefit of preventing CH_4 emissions (Denman et al., 2007; EPA, 2010a, 2011a; IPCC, 2007c; Mikaloff Fletcher et al., 2004a, 2004b).

2.2 Accounting for Biogenic CO_2 at Stationary Sources

A. Implications for Accounting Methodologies

The distinction between fossil and biogenic CO_2 emissions and the different timescales over which large reservoirs of carbon cycle back through the atmosphere (e.g., coal seams versus forest carbon)

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[15] Global production of N_2O is attributed largely to microbial processes. Bacteria produce N_2O through nitrification and denitrification, which are key processes within the natural nitrogen cycle. Nitrification is the main source of N_2O under aerobic conditions, while de-nitrification dominates under anoxic condition (EPA, 2010a).

have implications for the methodologies that are used to track the effects of anthropogenic emissions on the concentration of CO_2 in the atmosphere. The first implication is that, for quantifying the impact on the atmosphere of taking fossil carbon out of a long-term reservoir and turning it into CO_2 (i.e., by using it for fuel) at a stationary source, it is sufficient to estimate emissions to the atmosphere on the basis of when and where they occur. Fossil carbon reservoirs such as coal seams, oil and gas deposits, and peat do not regenerate on the several-century time scale that is relevant for GHG accounting. A straightforward estimate of emissions can be accomplished by calculating the amount of carbon in the fossil fuel, or by monitoring the concentration and flow through an exhaust system, stack, or vent. Many methodologies and technologies (e.g., ASTM standards, continuous emissions monitoring systems) exist for this purpose (CARB, 2008; EC, 2007; IPCC, 2006a; WRI/WBCSD, 2011).

A second implication is that in order to quantify the impact of transforming biologically based carbon from a terrestrial storage pool (such as above-ground biomass) into CO_2 via combustion, decomposition, or processing at a stationary source, it is necessary to quantify both emissions of CO_2 to the atmosphere from that stationary source and net changes in carbon stocks as the biomass grows and is used across all of the pools that store carbon. The feedstock- or measurement-based methods typically used for estimating CO_2 emissions from fossil fuels at stationary sources are equally suitable for estimating emissions of CO_2 from the combustion, decomposition, and processing of biogenic feedstocks at stationary sources. For emissions and removals occurring on land, such as in forestlands, croplands, grasslands, and other land-use types, there are well-established methodologies for quantifying plant growth, biomass accumulation, and carbon stock changes (EPA, 2011a; IPCC, 2006b; USDA Forest Service, 2011a). Thus, the stationary source CO_2 emissions arising from use of biogenic feedstocks can be balanced against carbon stock changes associated with feedstock growth.

A third implication is that an accounting approach for stationary sources must recognize that emissions of biogenic CO_2 to the atmosphere and removals of CO_2 from the atmosphere may occur in different places and at different times on policy-relevant timescales. For example, while CO_2 is clearly sequestered on the land where plants and trees grow, the emissions from combustion of wood chips made from trees harvested from a forest may occur at a stationary source in another county, state, or even another country. A single tree may take decades to accumulate carbon, but the carbon can be released back to the atmosphere in a matter of minutes if it is burned for fuel. On a larger scale, a forest can continue to accumulate carbon in some trees while others are harvested and used. The carbon stored in forest biomass may also remain stored in durable harvested wood products long after is the forest is harvested and the carbon removed. Furthermore the carbon coming into the stationary source may be emitted at that source, but some of it may leave the source in the form of products (ethanol or lumber) and, in turn, may or may not be emitted elsewhere. These differences in the timing and location of emissions and removals add significant complexity to the development of an accounting approach for biogenic CO_2 emissions at stationary sources.

B. Intergovernmental Panel on Climate Change Accounting Approach

The IPCC developed a foundational approach for addressing the complexities associated with accounting for biogenic CO_2 emissions and removals (IPCC, 1996) at the national level. The IPCC was tasked with developing guidelines for countries to estimate and report all of their anthropogenic GHG emissions to the United Nations Framework Convention on Climate Change (UNFCCC) in a consistent and comparable manner. Accordingly, the United States follows the IPCC accounting guidelines when it develops the annual Inventory of U.S. Greenhouse Gas Emissions and Sinks (Inventory) as part of its obligations under the UNFCCC.[16]

Recognizing that many anthropogenic factors influence emissions and sequestration in biological systems, the IPCC opted to account for these factors comprehensively and holistically in an assessment of the entire Land-Use Change and Forestry (LUCF) Sector (Apps et al., 1997). As a result, biogenic CO_2 emissions, which reflect the return to the atmosphere of carbon stored in biological systems, were assigned to the land areas where carbon is stored, regardless of where the emissions actually take place. The IPCC's accounting system thereby measures the changes in land-based carbon stocks for biomass systems and the flows of carbon for fossil-fuel systems in a different sector (e.g., Energy Sector). Using this approach, countries have been able to communicate the contribution of their land areas to the global build-up of GHG concentrations in a consistent manner. To maintain consistency and to prevent double counting, the IPCC's approach for countries to estimate emissions from their Energy Sectors requires that CO_2 emissions resulting from biologically based fuels not be included in Energy Sector totals:

Biomass Fuels: Biomass fuels are included in the national energy and emissions accounts for completeness. These emissions should not be included in national CO_2 *emissions from fuel combustion. If energy use, or any other factor, is causing a long term decline in the total carbon embodied in standing biomass (e.g., forests), this net release of carbon should be evident in the calculation of* CO_2 *emissions described in the Land-Use Change and Forestry chapter.*[17]

The IPCC accounting system provides an accurate reflection of global GHG emissions because countries are required to account for all anthropogenic emissions, and to account for them only once (i.e., there is complete accounting). Moreover, it is important to note that the IPCC does not make any value judgments about whether—within a given country—the producer or the consumer of biomass bears responsibility for the CO_2 emitted from use of the biomass. Rather, the IPCC approach ensures that countries acknowledge that gain or loss of stored carbon is occurring within their borders. The IPCC also eschewed any statements indicating that its decision to account for biomass CO_2 emissions in the Land-Use Sector rather than the Energy Sector was intended to signal that bioenergy truly has no impact on atmospheric CO_2 concentrations. In fact, the IPCC has stated the following on the Frequently Asked Questions section of its Web site:[18]

Biomass burning for energy cannot be automatically considered carbon neutral even if the biomass is harvested sustainably, there still may be significant emissions from processing and transportation etc. of the biomass. While CO_2 *emissions from biomass burnt for energy are reported as zero in the Energy Sector, the net* CO_2 *emissions are covered in the AFOLU Sector.*

The statements above indicate that the IPCC recognized that biomass energy use could have an impact on atmospheric CO_2 concentrations, and that a comprehensive approach to account for all sources and sinks at the national level would be able to quantify that impact.

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[16] The United States submits the Inventory to the Secretariat of the UNFCCC as an annual reporting requirement. The UNFCCC, ratified by the United States in 1992, sets an overall framework for intergovernmental efforts to tackle the challenges posed by climate change.

[17] Page 1.10. Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories: Reference Manual.

[18] IPCC Frequently Asked Questions: http://www.ipcc-nggip.iges.or.jp/faq/faq.html.

C. Application of the IPCC Approach to Stationary Sources

Within countries, at disaggregated levels, quantifying CO_2 emissions from the combustion of fossil fuel can be accomplished with a straightforward adaptation of the IPCC's standard methodologies at a smaller scale. The typical or "default" carbon content values and emission factors published by the IPCC can be applied directly to estimates from individual stationary sources that use fossil fuels. For example, natural gas carbon content does not vary greatly across the United States (IPCC, 2006a), and the application of the IPCC national emission factor approach can provide a reasonable estimate of CO_2 emissions from natural gas consumption at a single stationary source. Emissions inventories for fossil fuels are concerned only with where and when emissions occur.

The application of the IPCC approach, in which biogenic CO_2 emissions are attributed to the LUCF Sector rather than the Energy Sector, to account for CO_2 emissions from the consumption of biologically based feedstocks for an individual stationary source would lead to the outcome that these emissions are estimated as part of the land-based accounts but are not counted as part of the source's total emissions. The result is that the CO_2 emissions are not assigned to the stationary source, but rather to the landowners that supplied the feedstocks. At the same time, if there is no corresponding accounting or only incomplete accounting by landowners, then the overall effect is that no entity actually is assigned the emissions or bears responsibility for the emissions of CO_2 resulting from the use of biologically based feedstocks at stationary sources (Pena et al., 2011). The decision to assign responsibility for GHG emissions, however, is a policy choice rather than a technical one and the IPCC does not express any viewpoints on the topic.

Alternatively, policymakers could decide to assign responsibility for CO_2 emissions from biologically based feedstocks to the stationary sources at which the emissions occur. The IPCC approach would again be insufficient because the linkage between the production of biomass (i.e., the land) and the consumption of biomass (e.g., a stationary source) would be broken. The amount of CO_2 measured from the stack of a stationary source may not reflect the actual net impact on the atmosphere, because it does not consider emissions to and removals from the atmosphere associated with the production, harvesting, or transport of the biogenic feedstocks. The IPCC recognizes this limitation:

> *The IPCC methodologies are intended to estimate national, anthropogenic emissions and removals rather than life cycle emissions and removals. However the IPCC Guidelines can be used, with care for different purposes. For calculating emissions from substitutions, all the changes in emissions and removals must be accounted for (IPCC, 2011).*

As noted above, the success of the IPCC approach relies on the completeness of the accounting for all, or a large share of, the emissions—including sources and sinks.

D. Categorical Approaches

Categorical approaches for accounting for biogenic CO_2 emissions from stationary sources, which have been suggested in certain contexts (sometimes called "categorical exclusion" and "categorical inclusion") rely on blanket assumptions about biogenic CO_2 emissions at stationary sources without any assessment or adjustment of total onsite biogenic emissions estimated on the basis of information about growth and more generally the carbon cycle. As they are meant to be applicable for individual stationary sources and do not require complete coverage of all entities and sectors, these categorical approaches differ from the IPCC approach. These categorical approaches de-link the accounting framework from the carbon cycle processes, such as sequestration or decomposition, occurring offsite from the stationary source. Instead, they rely on broad assumptions about the nature of all biogenic feedstocks and CO_2 emissions under all conditions, without any assessment of the actual impact.

1. Evaluation of the Categorical Exclusion Approach

One way to account for biogenic CO_2 emissions from stationary sources is to automatically exclude these emissions from any accounting framework. This approach rests on the assumption that because it is theoretically possible to harvest and consume biologically based feedstocks in a way that does not add net biogenic CO_2 to the atmosphere, it is reasonable to assume that that this equilibrium state always exists and does not need to be tested. However, as explained above, biogenic CO_2 emissions will have zero net atmospheric impact only in cases where—over some time period and at some spatial scale—carbon sequestration equals carbon emissions. There are many examples of time periods and regions in which harvest and other carbon losses from land have exceeded growth, and thereby led to net CO_2 emissions (IPCC, 2000). An approach that makes a blanket assumption about the status of sequestration on land without any demonstration or assessment to justify a zero emissions status at the stationary source does not allow for the possibility that the use of biogenic feedstocks could, in some circumstances, lead to a decline in land-based carbon stocks. In addition, this type of categorical approach does not consider the potential effect of feedstock production or of the various factors that can influence sequestration, such as growth rates, regeneration, and carbon storage in soils. In these cases, emissions would exceed sequestration, and the theoretical condition required for biogenic CO_2 emissions to have no net impact on the atmosphere would be violated. While such a categorical exclusion is consistent with the exclusion of biogenic CO_2 emissions from the Energy Sector using the IPCC methodology, the IPCC approach assumes that any changes in stocks will be reported in the LUCF Sector and thus requires a full and complete accounting of land use and land-use change. Without that link to the carbon stocks on land, an approach that categorically excludes biogenic CO_2 emissions from stationary sources does not reflect the carbon cycle.

The failure of an accounting framework based on categorical exclusion to factor in the conditions on the land base can be illustrated with a hypothetical example. Consider a region in which 10 wood-fired electric generating facilities will be built. Over time, as these facilities are completed, they collectively begin to require more and more biomass. If forest carbon stocks in the supply region begin to decline as a result of this increased bioenergy capacity, a corresponding increase in atmospheric CO_2 will occur, yet the sources will report that they are producing zero emissions. At the same time, there will be no accounting for declining carbon stocks in the forests that supply the wood. An approach that categorically excludes the biogenic CO_2 emissions at the stationary source from accounting, while failing to provide an accounting of changes in carbon stocks on land, does not recognize the carbon cycle or allow for any assessment of adjustment of a stationary source's total onsite biogenic emissions.

2. Evaluation of the Categorical Inclusion Approach

Another way to account for biogenic CO_2 emissions from stationary sources is to automatically include all of these emissions in the total onsite CO_2 emissions at the stationary source (i.e., "categorical inclusion"). Like categorical exclusion, this type of approach does not allow for any assessment or adjustment of a stationary source's total onsite biogenic emissions based on information about growth and/or avoidance of emissions and more generally the carbon cycle. As discussed earlier, unlike the combustion of fossil fuels, which inevitably results in an increase in atmospheric CO_2 over a policy-relevant time frame, such an outcome is not inevitable with the consumption of biologically based feedstocks. The amount of biologically based feedstocks consumed at stationary sources during a year may be partially or completely balanced by the amount of feedstock that grows during the year. Without that link to the carbon stocks on land, an approach that categorically includes biogenic CO_2 emissions from stationary sources does not reflect the carbon cycle.

The failure of a categorical inclusion approach to allow for the possibility that sequestration on land may counteract direct emissions of biogenic CO_2 from a stationary source can be illustrated with a hypothetical example. Consider the same region above, in which 10 wood-fired electrical generating facilities will be built. Over time, as the facilities are constructed they begin to use more and more biomass, and they emit more and more biogenic CO_2. At the same time, forest growth is occurring in the region where the feedstock is harvested. An approach that categorically includes the biogenic CO_2 emissions at the stationary source in the accounting, while failing to provide an accounting of changes in carbon stocks on land, does not recognize the carbon cycle or allow for any assessment of adjustment of a stationary source's total onsite biogenic emissions.

E. Lifecycle Emissions Analysis

Another approach that has been used to assess the impact of biogenic CO_2 emissions is a lifecycle emissions analysis (Berry et al., 1998; EPA, 2010c; Heller et al., 2004; Heller et al., 2003; Keoleian and Volk, 2005; Mann and Spath, 1997; Spath and Mann, 2004; Spitzley and Keoleian, 2005). A lifecycle emissions analysis, if conducted appropriately, can provide perhaps the most comprehensive way to assess a biogenic fuel's net emission impacts compared with the net emissions from fossil fuels, where both fossil and biogenic fuels are evaluated on the same or very similar terms. However, as explained earlier, this report and the framework presented in Sections 4 and 5 provide a means to address a different, somewhat narrower issue: namely the appropriate way to adjust a stationary source's total onsite biogenic emissions based on information about the carbon cycle. The framework presented here is not intended to look at broader impacts or compare the net impacts of biogenic and fossil-based CO_2 emissions. As such, it differs from lifecycle analysis[19] and does not include significant GHG emissions such as N_2O from fertilizer application, or CO_2 emissions from fossil fuel combustion related to harvesting, processing, and transport of biologically based feedstocks. The more limited type of approach in this framework keeps the assessment of biogenic emissions at a stationary source as similar as possible to the evaluation of fossil fuel emissions at a stationary source, while still acknowledging the role of the carbon cycle.

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[19] Lifecycle analysis is a compilation and evaluation of the inputs, outputs, and the potential environmental impacts of a product system throughout its life cycle. In the context of GHG assessments, lifecycle GHG emissions are the aggregate quantity of GHGs related to the full fuel cycle, including all stages of fuel and feedstock production and distribution, from feedstock generation and extraction through distribution and delivery and use of the finished fuel.

3 Technical and Methodological Issues for an Accounting Framework

Section 3 identifies and describes important technical and methodological issues that should be considered when constructing any framework for developing an adjustment factor for biogenic CO_2 emissions at stationary sources that reflects changes in carbon stocks that occur beyond the stationary source. Decisions on these factors are critical in development of an accounting framework, and may be different depending on program and policy requirements and objectives. Section 3 presents an overarching discussion of these issues, along with the implications of specific decisions. Then, Sections 4 and 5 present the accounting framework and explain the decisions EPA made in its development.

This section covers the following technical and methodological issues:

- Gases to Include
- Direct Emissions
- Feedstock Losses During Transportation and Storage
- Carbon Contained in Products and Byproducts
- Feedstock Growth: Emissions and Sequestration on Land
- Waste Materials
- Land-Use and Management Changes
- Temporal Scale
- Spatial Scale
- Baselines
- Biogenic Feedstock Categorization and Disaggregation

3.1 Gases to Include

The inclusion or exclusion of particular GHG within the context of an accounting framework depends upon the intended goals and applications of that framework. For an accounting framework that seeks to quantify the full net atmospheric GHG impact of using biogenic material as a feedstock in a stationary source context, all six GHGs would be included. However, in an accounting framework that seeks to adjust total onsite biogenic emissions on the basis of the carbon cycle, only gases involved in the carbon cycle might be included; other non-CO_2 GHGs might be categorized as outside the scope of the analysis.

3.2 Direct Emissions

Direct emissions occur at the stationary source when the carbon in a biogenic feedstock is transformed to CO_2 via combustion, decomposition, or another process such as fermentation. Direct emissions can be estimated from the quantity of biogenic feedstock that is processed at the stationary source, or they can be measured as they leave the source via standard monitoring technology (e.g., continuous emissions monitoring system). These emissions contribute CO_2 to the atmosphere directly and should be considered a critical component of the accounting framework. Similar to measuring direct biogenic CO_2 emissions, there are methods to estimate CH_4, N_2O, and hydrocarbons if these gases are included in an accounting framework.

3.3 Feedstock Losses During Transportation and Storage

As the biologically based feedstock moves from the production site to the stationary source, losses may occur due to transportation, storage, and handling. For example, some of the material harvested from a farm (e.g., switchgrass) may be lost from the truck while in transit, or decay might occur while the feedstock is in storage at the stationary source (Qin et al., 2006). These losses are nearly always zero or minor, and likely depend on the biogenic feedstock material that is harvested or collected.

Accounting for these emissions is important because these losses occur between the feedstock production site and use at the stationary source, and therefore any assessment of a stationary source's onsite biogenic CO_2 emissions based on feedstock production alone would likely be an overestimate. Similarly, if such losses do occur, a measurement of direct CO_2 emissions from the stack or vent at the stationary source would likely be an underestimate of the total net biogenic CO_2 emissions from the feedstock. The amount of feedstock that is ultimately used in the stationary source is the difference between the total feedstock that was produced at the farm or forest and any feedstock losses experienced during transportation and storage. Inclusion of these losses as a term in an accounting framework, then, depends on whether the biogenic CO_2 emissions are estimated at the stationary source as: (1) direct emissions from the stack or vent, (2) a function of feedstock produced, or (3) a function of feedstock received at the stationary source.

Accounting for these losses allows for the linkage between the stationary source that uses the feedstock and the sequestration that occurs offsite. It ensures that there is a mass balance to account for all of the carbon fixed at the feedstock production site. While this term is likely to be small, for completeness it may be included in the accounting framework. However, depending on the program and policy requirements and objectives, it may or may not be important to capture these types of biogenic CO_2 emissions.

3.4 Carbon Contained in Products and Byproducts

Once the feedstock has entered processing at the stationary source, it may be transformed into products (such as paper or ethanol) that then leave the stationary source. An accounting framework could account for the ultimate fate of carbon contained in any products or byproducts[20] created by the stationary source. Depending on the product, the carbon may subsequently be released elsewhere after leaving the stationary source, or it may be sequestered. Some of these product flows may be minor compared with the feedstock that is used (e.g., unoxidized carbon in post-combustion ash), some may be fuels that will be oxidized later (e.g., ethanol), and others may be durable products that will be converted to CO_2 over longer timeframes (e.g., lumber, harvested wood products). Emissions associated with the use of products or byproducts (e.g., combustion of ethanol as a fuel) typically occur outside of the stationary source. As a result, it may be necessary to calculate the amount of carbon that passes through the source to other users, but is not released as biogenic CO_2 emissions from the stationary source. In some cases, carbon is contained in post-combustion byproducts such as fly ash or biochar[21] that are themselves sequestered, and thus that carbon does not exit the stack as CO_2 emissions. An accounting framework may consider these types of products as well. Finally, if a stationary source employs carbon capture and storage (CCS) technologies, it may

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[20] A byproduct is a material of value produced as a residual of, or incidental to, the combustion process.

[21] Biochar is charcoal created by pyrolysis of a biogenic feedstock.

be appropriate to include biogenic CO_2 emissions stored by such technologies within an accounting framework.

3.5 Feedstock Growth: Emissions and Sequestration on Land

Biogenic CO_2 emissions and sequestration in feedstock growth on land can be divided into two categories:

- Sequestration in growth of the feedstock itself.
- Additional emissions or sequestration on land associated with feedstock production (i.e., changes in the amount of carbon on the landscape where feedstock is produced, such as changes in soil carbon due to changes in management regimes).

For the first category, growth of the feedstock may sequester some or all of the CO_2 emitted directly from the stationary source over time, and should be considered. CO_2 that is released when the feedstock is used at the stationary source was originally stored in the biological material harvested to produce the biogenic feedstock. Contemporary carbon sequestration in biologically based feedstock growth can, under the right conditions, be roughly equal to direct emissions and thus in balance with emissions over some period of time and at some spatial scale.

Accounting for this component can require slightly different considerations when it is an agricultural versus a forest feedstock, largely due to feedstock characteristics such as growth patterns. For many agricultural feedstocks that grow and are harvested annually, it may be reasonable to assume that atmospheric CO_2 during growth of the feedstock itself will equal the direct biogenic CO_2 emissions from use in the stationary source.[22] For forest feedstocks that grow over longer periods of time across landscapes that are significantly larger than the area actually harvested each year, there are additional complexities, as discussed later.

The second category recognizes other potentially important shifts in carbon stocks in other pools on land, such as soil carbon. Carbon is exchanged between pools on land in a number of different ways (e.g., aboveground biomass is transferred to dead organic matter and eventually soil carbon pools, and there are losses of CO_2 as carbon moves between the pools due to biogeochemical and physical processes), and a gain or loss in carbon in any single pool does not necessarily indicate a net effect on atmospheric CO_2.

3.6 Waste Materials

The carbon contained in waste materials (e.g. MSW, manure, wastewater, construction debris) generally has one or more of three fates: emission as CH_4, emission as CO_2, or long-term storage in the waste material (e.g., carbon storage in landfills) (EPA, 2011a).

Methane is generated through the decay of wastes under anaerobic anthropogenic management (e.g., in landfills, manure lagoons, and wastewater treatment systems) (EPA, 2011b; IPCC, 2006c). Emissions of CH_4 to the atmosphere have a higher GWP than CO_2, and are considered to be anthropogenic (IPCC, 2007c).

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[22] The zero carbon stock change assumption for annual crops can be found in IPCC (2006b).

Carbon dioxide is emitted from waste management through several routes. It is released as wastes decay aerobically (either through anthropogenic management, or natural decay) (IPCC, 2006c, 2007c). It is also released (though in smaller proportions) through anaerobic waste management (IPCC, 2007c). Combustion of waste materials produces CO_2, as does the combustion of any captured waste-derived CH_4 (IPCC, 2007c).

Depending on the conditions in the landfill, some carbon in waste may not degrade into CH_4 or CO_2 and may instead be stored over long time period, perhaps on the order of hundreds of years. A substantial fraction of the carbon in wood and certain types of paper, for example, decay very slowly and accumulate in landfills. Carbon fractions in other waste types decay over varying time periods (De la Cruz and Barlaz, 2010; IPCC, 2006a).

3.7 Land-Use and Management Changes

It is important to examine how carbon flows between different pools and how carbon stocks change in response to land-use activities and changes in those activities as part of the development of an accounting framework for biogenic CO_2 emissions at stationary sources.[23] Depending on the nature and quantity of land that is converted from one land-use type to another, the implications of land-use change for carbon stocks could be fairly minimal to quite large (IPCC, 2000). In fact, land-use change emissions (which are primarily biogenic) are responsible for about 30 percent of total anthropogenic emissions since 1850 (CDIAC, 2011), and therefore land-use change emissions contribute about 30 percent to total present-day CO_2 forcing. Two types of land-use change—direct and indirect—are relevant for biogenic feedstock production and are discussed below (Fritsche et al., 2010). Land-use management changes[24] are changes associated with management activities that affect the carbon stocks and fluxes on that landscape without a conversion to a different land use. Examples of land management change are:

- Changing harvest regimes to include collection of woody residues in already-managed forests,[25] which can decrease residue contribution to soil carbon stores (Peckham and Gower, 2011; Repo et al., 2011);
- Changing from conventional tillage[26] to reduced tillage management practices, which causes less disruption of carbon stored in the soil and less related CO_2 emissions (Ogle et al., 2005; West and Marland, 2002; West and Post, 2002); and
- Removing crop residues which can decrease soil carbon stores.

A. Direct Land-Use and Management Changes

Direct land-use change will occur if land within the system boundaries of an accounting framework is brought into production for a biogenic feedstock that was previously in another land use (such as

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[23] According to the IPCC, land use is the total of arrangements, activities, and inputs undertaken in a certain land cover type (a set of human actions) and the social and economic purposes for which land is managed (e.g., grazing, timber extraction, conservation) (IPCC, 2000).
[24] Land-use change refers to a change in the use or management of land by humans, which may lead to a change in land cover (IPCC, 2000, 2006b).
[25] Managed forests are all forests subject to some kind of human interactions (notably commercial management, harvest of industrial roundwood (logs) and fuelwood, production and use of wood commodities, and forest managed for amenity value or environmental protection if specified by the country), with defined geographical boundaries.
[26] Tillage is defined as agricultural preparation of the soil by mechanical agitation.

converting cropland into switchgrass feedstock production). For example, direct land-use change might occur if conversion of cropland or grassland to forestland occurs to provide wood for a biomass energy stationary source, which is likely to increase the biomass carbon stocks on land (Houghton et al., 1999). At the same time, soil carbon levels would probably increase or remain fairly stable (Post and Kwon, 2000). If demand for switchgrass increased, with resulting conversion of cropland to switchgrass production, then there would likely be an increase in soil carbon stocks due to increased root biomass and decreased soil disturbance (i.e., planting, tillage) (Anderson-Teixeira et al., 2009). Alternatively, if commodity demand caused increased conversion of forestland to cropland, it is likely that there would be decreases in all five carbon pools associated with the production of forest-derived feedstock (IPCC, 2000). Inclusion of direct land-use change in an accounting framework is critical in terms of accounting for the emissions and sequestration that occur at the production site for the feedstock ultimately used at the stationary source. Without this consideration, there is not a connection between the land and the stationary source.

B. Indirect Land-Use Change and Leakage

Indirect land-use change might result when new market demand for a biologically based feedstock reduces the supply of commodities from lands, or commodities diverted to feedstock development, which in turn raises prices and can stimulate replacement production elsewhere, thereby increasing GHG emissions outside the accounting boundary (Barrett, 1994; Murray et al., 2004; Stavins, 1997). This is often referred to as "leakage."[27] Leakage and indirect land-use change (EPA, 2007; Searchinger et al., 2009) are often discussed together and in the context of biologically based feedstock production. Therefore, while leakage can occur from use of any energy feedstock (including fossil fuels), its connection with indirect land-use change and the potential for biogenic CO_2 emissions make them important issues to consider in developing an accounting framework for biogenic CO_2 emissions at stationary sources.

Indirect land-use change and related leakage can manifest itself in a number of ways. Consider an example involving forest carbon sequestration. Suppose, because of an increase in woody material-based bioenergy production, the volume of timber harvest making its way into the non-bioenergy market is reduced in the Pacific Northwest (PNW). Because less project-area timber is now available, traditional buyers look for additional timber from other sources. This causes timber prices to rise, and additional harvest or management changes increase production in other regions, leading to increased emissions of otherwise sequestered carbon in these other regions. For example, reductions in timber harvest on PNW public lands in the 1990s were matched by accelerated rates of harvest on PNW private lands, as well as by harvest on lands in Canada and in the southern United States (Murray et al., 2004; Wear and Murray, 2001). In this case, the increase in sequestration in one region caused a decline in sequestration elsewhere; the decline in sequestration was estimated at roughly 85 percent of the sequestration increase. These types of emission and sequestration effects may or may not be important, depending on the program and policy requirements and objectives.

Leakage—in the circumstances where it is likely to be a significant factor—could be included in an accounting framework for biogenic CO_2 emissions at stationary sources. In those cases, the framework could describe the market impacts that can cause leakage and, where appropriate and possible, quantify its effects on net emissions. Specifically, estimation of leakage may be important in cases when:

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[27] Leakage refers to the indirect impact that a targeted activity in a certain place at a certain time has on carbon storage at another place or time. Leakage may include carbon flows that are large and predictable. (see IPCC, 2007a).

- The new bioenergy use diverts supply of feedstock that would otherwise have gone into an existing marketplace (e.g., using pulp logs or hay for bioenergy that otherwise would have been sold on the market).

- The land on which the biogenic feedstock is grown was previously growing products that went into an existing marketplace (e.g., when switchgrass is grown on lands that were previously growing corn, the absence of that corn from the market place could cause leakage and additional emissions with conversion of land to cropland for corn production).

C. Land-Use Change and Carbon Debt

Another issue that is often raised in relation to biogenic CO_2 emissions and land-use change is carbon debt.[28] While this issue may not be included directly as a term in an accounting framework for biogenic CO_2 emissions from stationary sources, it is still important to consider its relation to land use and its potential implications depending on the policy or program. Two recent studies (Fargione et al., 2008; Searchinger et al., 2009) highlighted the importance of considering both land-use and land-management change in assessing net GHG impacts of biomass energy. Fargione et al. (2008) introduced the term "carbon debt" to describe the net GHG implications of conversion of lands with substantial carbon stocks to intensive production of an annual feedstock. The new use of the land would result in higher rates of annual CO_2 uptake that yielded a renewable, annual biomass feedstock stream. That feedstock could be used to substitute for a fossil fuel, but the land where it was produced would, in the specific cases they considered, have much lower average carbon stocks (both live and dead, above- and belowground) than the ecosystem displaced when the land was put into production. This net change in carbon stocks associated with land-use change was termed a "carbon debt."

Fargione et al. (2008) noted that the carbon debt was not necessarily "incurred" only in the first year after land-use change, but could happen gradually as, for instance, soil carbon pools present before land-use change gradually declined due to higher rates of soil organic matter decomposition stimulated by the new land use. To put the carbon debt into perspective, Fargione et al. (2008) calculated the "revenue" from the new land use, calculated in terms of reduced net emissions due to potential displacement of fossil fuel CO_2 and other GHG emissions. Thus, the number of years required to "pay back" the carbon debt—i.e., the number of years before the summed annual "revenues" exceeded the calculated carbon debt—varied widely among the different combinations of: (1) prior land cover, (2) feedstock type, and (3) energy production technology they considered.

The arguments presented by Fargione et al. (2008) apply to any direct or indirect land-use or land-management change that results in a net change in the total carbon stocks over a land base (either the specific land base used in production, or a larger land base if there are indirect effects). As an example, the initiation of a new forest management regime that involved routine collection of woody debris from the forest floor would reduce annual inputs of carbon to the soil, and would likely cause a gradual reduction in forest floor and soil carbon pools (Peckham and Gower, 2011; Repo et al., 2011). The ecosystem would presumably eventually equilibrate at a new (lower) level of carbon stocks, and the difference from previous levels would represent a carbon debt according to Fargione et al. (2008).

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[28] Carbon debt is defined as the net GHG implications of conversion of lands with substantial carbon stocks to intensive production of an annual feedstock.

More recently, a study by the Manomet Center for Conservation Science (2010) used the concept of carbon debt in a very different way to address net CO_2 emissions for biomass feedstocks generated from forest management. The Manomet "carbon debt" focuses on differences in the efficiency of energy production from biomass versus fossil fuel feedstocks, rather than as a consequence of land-use or management change. Specifically, the study quantified carbon debt as the difference between the total carbon harvested for biomass and the carbon released by fossil fuel burning that produces an equivalent amount of energy (Manomet Center for Conservation Sciences, 2010). Manomet then used a forest simulation model to estimate the time it would take for forest growth to equal that amount of carbon debt. The Manomet study also differed from most other recent analyses in its choice of spatial and temporal scale for its analysis (i.e., a forest stand, analyzed over a long time period).

The carbon debt issues raised by Fargione et al. (2008) and Searchinger et al. (2009) are relevant regardless of spatial and temporal scale of analysis. It is important to note, however, that the calculation of carbon debt used by Manomet (2010) is heavily dependent on the design of that analysis, specifically on the choice of baseline and scale. Thus, definitions of baselines, as well as the spatial and temporal scales of analysis, have important implications for calculation of net emissions from biomass energy facilities (as discussed in the next subsection).

The concepts of carbon debt and payback period (as used by Fargione et al. (2008) rather than Manomet Center for Conservation Sciences (2010)) provide a graphic illustration of the relative GHG implications of different combinations of land-use conversion, feedstock type, and energy production technology. The calculations of both the carbon debt and the payback period integrate a wide range of factors related to carbon emissions and sequestration, but do not explicitly allow calculation of net CO_2 emissions over time from any given stationary source.

The form of carbon debt relevant to stationary source accounting is incurred when there is a reduction in long-term average carbon stocks on an area of land, when the land is converted from a prior land use (typically with high levels of carbon stocks) to a land use devoted to production of a biomass feedstock (but typically with lower levels of carbon stocks). The magnitude of the debt is a function of the difference in the long-term average carbon stocks under the two land uses. The debt is incurred over the period of time that the system moves from the old carbon stock level to the new level, and the change over time can be annualized. As stated earlier, it may or may not be necessary to consider these concepts in an accounting framework for biogenic CO_2 emissions from stationary source.

3.8 Temporal and Spatial Scale

Time provides one of the basic boundaries for describing GHG emissions to the atmosphere. For example, emissions are generally accounted for over a calendar year (UNFCCC, 2006). This is true in the U.S. GHG Inventory, which is an annual report, as well as many existing regulatory programs (e.g., the U.S. GHG Reporting Program) that have annual reporting requirements. Also, depending on the type of emissions estimate or the source or sink being measured, it may be more practical to use an average value over a period of years. For example, it may be very expensive or otherwise undesirable to collect data annually. Emissions may vary from year to year with weather or market conditions, or there may be a long-term increasing or decreasing trend. When developing an accounting framework for biogenic CO_2 emissions from stationary source, it is important to recognize that the temporal and spatial scales of accounting may interact. In essence, averaging over space may yield the same numerical result as averaging over time, but the implications can be quite different.

Determining the spatial scale for an accounting framework has implications related to measurement, precision of estimates, and cross-boundary exchanges. The balance between emissions and sequestration is an important factor in assessing biogenic CO_2 emissions from stationary sources, and an accounting framework needs to have the appropriate spatial scale to assess that balance.

The first element of spatial scale is the size of the geographic area under consideration (e.g., international, national, regional, state, local). While in some cases the national scale would be appropriate (e.g., the Inventory), in other cases the assessment should occur at a smaller scale such as regional or state. For example, it would be possible for forest harvest to have no measurable impact on carbon stocks when reported at the aggregate national scale, even though carbon stocks may be declining in some areas and increasing in others.[29] Similarly, a national scale for agricultural biomass production might mask regional and local differences in length of the growing season, yield per acre, above- and below-ground net primary productivity, management practices (e.g., tillage or amendment application), previous land-uses (in the case of land-use conversion), and soil type and texture (Eagle et al., 2010). Reporting changes in carbon stock for forest systems at the national scale would similarly mask important regional differences in terms of growth rates, species composition, and climate. Waste materials also have important regional considerations that may not be captured at the national scale, including the composition of waste and regional climate factors that affect the rate at which organic waste decomposes into CH_4 in managed landfills.[30]

One difficulty introduced by defining the spatial scale with a geographic boundary (e.g., states, or aggregating counties and/or states to form regions) is accounting for transfers across boundaries. It is quite common for wood-using mills in one state to purchase and transport wood across state or regional boundaries (Teeter et al., 2006). Thus, the emissions from biogenic feedstock production may occur in a different region than the sequestration in the forest source area. In an accounting framework, this introduces complexity in that biogenic feedstocks of the same type acquired from different regions should be accounted for separately. In this situation, stationary sources would need to anticipate and/or monitor the source region for all feedstocks.

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[29] The dramatic differences possible when evaluation is conducted at a state versus regional scale can be illustrated by the impact of hurricane Hugo on South Carolina's (SC) forest resources. In 1989, Hugo hit SC and caused extensive damage to the state's forests. The hurricane reduced the inventory of softwood (e.g., pine) growing stock by 21 percent or 1 billion cubic feet (Sheffield and Thompson, 1992), which is equivalent to more than two years of the previous average forest harvest across the entire state (Tansey, 1986). After the hurricane, the removals of softwood timber in the state exceeded the net growth by 43 percent (Conner, 1993), whereas before the hurricane net growth exceeded removals by 2 percent (Tansey, 1986). However, in the subsequent national assessment of forest resources (Haynes et al., 1995), southern softwood net growth exceeded harvests. Thus, the deficit situation in SC resulting from the hurricane impact was not observed in the larger region of the south, and applying regional southern assumptions regarding balance between growth and removals to SC could have led to additional unsustainable pressure on the resource.

[30] The composition of MSW varies regionally across the United States due to: (1) variations in climate and local waste management practices that greatly influence the generation of yard trimmings; (2) variance in the generation of certain products such as newspapers and telephone directories—primarily between urban and rural areas; (3) the level of commercial and economic activity in a region, and the characteristics of the local economy, and (4) local and state regulations such as landfill bans, bottle bills, and variable-rate pricing systems, which can influence the amount and composition of materials available for diversion from the landfill (EPA, 2010b). Regional climate factors such as annual rainfall affect CH_4 emissions from waste in a landfill. For example, a pound of organic waste landfilled in arid areas of the United States could decay at approximately one-half to one-third the rate of organic waste landfilled in non-arid areas (EPA, 2011b).

In addition to inter-regional considerations, international feedstock production and the imports and exports of those feedstocks can significantly affect overall biogenic feedstock resource availability and demand pressures on those resources. The pricing and flow of feedstocks and related commodities have the potential to significantly affect domestic supply chains. The spatial scale for an accounting approach could either include or exclude international biologically based feedstocks, depending on policy requirements and international agreements related to GHG emissions accounting.

The characteristics of the land base are another consideration related to spatial scale. For example, while the ratio of forest growth to harvest at the national scale is roughly 1.71 (Smith, W. B. et al., 2009), it varies substantially with geographic region, species, and ownership. The ratio of forest growth to harvest for private forests in the conterminous United States is 1.3, while the same ratio on public lands is 5.3 (DOE, 2011). An area with a large proportion of publicly owned land would therefore be more likely to have lower levels of harvest (and higher levels of growth) than a similar area with more private land ownership (DOE, 2005, 2011).

Ideally, an accounting framework would allow for a distinction between "working" and "reserved" lands. For instance, if all forestland is included in the calculation of changes in carbon stocks, then intensive harvests on "working" forests could be offset by carbon sequestration on "reserved" lands. However, there is an active debate about just what constitutes the working forest land base (i.e., Alig et al., 2002). Some fraction of the land base is "reserved" by legal limits on logging, and there is clearly a significant fraction of the remaining forest land that is not available for harvest because of a wide range of biological, physical, legal, economic, and social concerns (Buchholz et al., 2010; Butler, 2008). These limits on the availability of working forest land are difficult to quantify and may vary over time. For example, the increasing "parcelization" of forest land (i.e., subdivision into smaller ownerships) is generally assumed to reduce the land available for harvest because harvest operations are impractical on very small landholdings. The minimum effective size of a working forest may well change over time, however, with changes in harvest technology and/or commodity prices.

Another element that can influence the choice of spatial scale is the availability and accuracy of data. When a stationary source purchases biologically based material for energy production, it is possible to measure every ton of material that is purchased or brought into the stationary source (e.g., using measurement equipment such as scales and monitors). However, when estimating the biologically based resource in a source area, it is necessary to use sampling approaches, which are inherently less precise than complete measurements. For example, to estimate woody biomass in the forests of a region, trees on inventory plots (samples) are measured periodically (FAO, 1997). Tree measurements (e.g., species, diameter, height) are used in conjunction with mathematical models to estimate biomass per tree and then statistically expanded to obtain estimates of biomass per unit area of forest (FAO, 1997). Remote sensing approaches (e.g., satellite imagery, aerial photography) are used to determine the area of forest cover within a region (FAO, 1997).[31]

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[31] The primary source of forest biomass information in the United States has been the Forest Inventory and Analysis (FIA) program of the United States Department of Agriculture Forest Service (EPA, 2011a). The FIA program collects information from more than 125,000 forested ground plots and approximately 280,000 non-forested ground plots on all types of forest ownerships (USDA Forest Service, 1992). The sample intensity for the field measurement phase is approximately one inventory plot per 6,000 acres (2,362 hectares) of forestland (USDA Forest Service, 2011b). Furthermore, plots are remeasured, at best, about once every five years (USDA Forest Service, 2011b). For example, consider a geographic area within 50 miles of a facility in which forest accounts for 60 percent of land cover. Of the approximately 5 million acres of land within the 50-mile radius, 3 million acres would be expected to be forested. For 3

Data accuracy is affected by the land area considered in the accounting framework. When larger land areas are considered in an estimate from Forest Inventory and Analysis (FIA) or other sample-based data, the increase in sample size provides more precision (i.e., smaller sampling errors) in estimates. Conversely, when much smaller land areas are considered, sampling error may become so large as to render FIA-based estimates unreliable. In those cases, estimates must be derived from other sources such as special inventories or surveys. For a very small area (e.g., hundreds or thousands of acres of plantation owned and managed by a stationary source), this information may be available from inventories conducted as a part of standard forest management practices.

3.9 Defining Baselines

A baseline is any datum against which change is measured. Such a datum serves as the reference against which other conditions or changes can be compared. It might be a "current baseline" that represents observable, present-day conditions. It might also be a "future baseline" that represents a projected future set of conditions, excluding the driving factor of interest (for example, use of biogenic feedstocks at stationary sources). Alternative interpretations of the reference conditions can give rise to multiple baselines (IPCC, 2007b).

In the context of this report, an accounting framework requires a baseline against which the impact of biogenic feedstock production and use can be compared. The determination of what baseline to use can make a significant difference in the calculated BAF and will likely depend on the specific context(s) in which the accounting framework is applied.

Baselines have been defined in at least three ways in earlier studies. These three approaches can be characterized as focusing on: (1) the net change from a current reference point (e.g., Fargione et al., 2008) (referred to below as the **Reference Point Baseline**), (2) the net change from a bounded business-as-usual future (e.g., Searchinger et al., 2009) (**Anticipated Future Baseline**), and (3) the net change from an alternative future (e.g., Manomet Center for Conservation Sciences, 2010) (**Comparative Baseline**).

A. Reference Point Baseline

As discussed in Fargione et al. (2008), the reference point baseline approach seeks to answer the question, "Is there more or less carbon stored in the system (the stationary source and its feedstock-supply source) at the end of an assessment period than there was at the beginning?" This approach establishes as the baseline the carbon stock on a given land base (i.e., total stocks of organic and inorganic carbon stored in vegetation and soils) at a given point in time (or time interval). It is against this measureable reference point that future stocks will be measured. If stocks increase or remain constant from that level, then this approach would conclude that the biogenic feedstock source region itself is not contributing to an increase in CO_2 concentrations, and therefore stationary source emissions of CO_2 from consumption of biologically based feedstocks from this region are also not contributing to an increase in CO_2 concentrations. Conversely, if stocks decline from that

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million forest acres, about 500 FIA plots would be expected, with about 100 plots measured annually on a continuing cycle. Because these plots may be expected to fall in a wide range of forest conditions (e.g., different forest types, ages, ownerships, site productivity classes, and management regimes), there will be variability in an estimate of the average biomass per forest acre. For example, the total forest biomass within 50 miles of Appomattox, Virginia, is estimated to be 140.7 million tons with a sampling error of 4.2 percent (5.9 million tons).

level, the feedstock production area and the stationary source(s) using biologically based feedstocks from that area are likely contributing to that decline and related net emissions.

To develop the value for the baseline under this approach, it is appropriate to look retrospectively at carbon stocks in the present and in the recent past. This baseline could include a value from carbon stocks in one year or an average over a range of years.

B. Anticipated Future Baseline

The anticipated future baseline approach seeks to answer the question, "Is more or less carbon stored after the assessment period in the system (the stationary source and its feedstock-supply source) *than expected*?" This approach, as used by Searchinger (2009), takes an expected rate of change in carbon stocks (for example, the rate of carbon sequestration) as the baseline. A complexity with this approach lies in how to define what would have been expected—in other words, to identify the expected rate of change in the absence of an energetic use of biomass.

The anticipated future baseline approach first takes into account the simulated "business-as-usual" (BAU) carbon stock levels in a region in a future period (for example, five years), without any new use of biogenic feedstocks for energy at stationary sources in that region. This BAU baseline could be established through various means, such as dynamic modeling or extrapolation of historic trends. The simulated future scenarios would then be compared with the observed carbon stock levels at the end of the time period. If observed carbon stocks equaled or surpassed predicted levels, then the conclusion would be that the source region, and the stationary source using biologically based feedstocks from the source region, did not contribute to an increase in net CO_2 concentrations *beyond what was expected* (i.e., there was no net flux of carbon to the atmosphere beyond what was expected). If observed carbon stocks are less than predicted levels, then the conclusion would be that the source region and the stationary source using the biologically based feedstock did contribute to an increase in net CO_2 concentrations *beyond what was expected* through a net flux of carbon from the forest to the atmosphere.

As it uses estimates of anticipated changes in carbon stock levels as a reference, the anticipated future baseline approach could detect a contribution to net CO_2 concentrations even when a region is accumulating carbon, if the accumulation is less than expected. The result would be a conclusion that stationary source emissions of biogenic CO_2 do have a net contribution to atmospheric CO_2. Similarly, this approach could reflect no increase in net CO_2 concentrations when a region is actually losing carbon, if the loss is less than expected. An analysis under these conditions might conclude that biogenic emissions from the stationary source do not have a net contribution to atmospheric CO_2.

C. Comparative Baseline

As used in Manomet (2010), the comparative baseline approach seeks to answer the question, "How do net emissions to the atmosphere, including the stationary source using biologically based feedstocks, differ from emissions that would have been expected if that stationary source was not in place or used other fuel feedstocks?" In other words, "Without the stationary source using biogenic feedstocks, how would the energy demand have otherwise been met and how would the total of CO_2 emissions have been different?" Like the anticipated future baseline approach, this approach uses the rate of change in carbon stocks, but it enlarges the system boundaries to examine alternative ways of providing the desired service. In this case, a comparison is conducted between outcomes using the biologically based feedstock versus other fuel feedstock types that might otherwise have been used. This type of approach could be useful when evaluating full lifecycle impacts, and extends beyond the stationary source being analyzed.

D. Differences Among and Implications of Choosing These Baseline Options

The fundamental difference among these approaches relates to the question being asked. The reference point approach answers the question "is the region gaining or losing carbon to the atmosphere?" More specifically, it asks "is the theoretical condition required for biogenic feedstocks to have no net CO_2 impact on the atmosphere from losses of land-based biomass (i.e., that land-based carbon stocks are not declining) being met?" The answer will show whether the atmosphere gained or lost CO_2 from, at least in part, production and use of the biogenic feedstocks in a region. The reference point approach does not address questions beyond changes in biospheric carbon stocks, such as the amount of fossil-fuel-based energy required to produce and deliver the biomass. The anticipated future approach answers the question "how does the rate of change in carbon stocks compare with what was expected?" In other words, it asks, "is the region gaining or losing carbon faster or slower than expected?" The answer is fundamental for understanding emission trends and the effects of certain policies, as well as for designing policies to lower overall emissions. Like the reference point approach, the anticipated future approach does not address questions beyond biospheric carbon stocks, such as the energy required to produce, process, and use energy, or about alternative ways of using biomass or meeting energy demands. Finally, the comparative approach builds on the anticipated future approach to add a comparison with the expected emissions from other potential fuel feedstocks, such as fossil fuels.

In essence the first approach addresses the observable change from the initial condition, while the second and third approaches include progressively greater elements of the opportunity cost, which explains what the outcomes would be if alternative futures and different system descriptions are compared. The choice of baseline determines how the comparison with the observed condition is represented, and thus ultimately determines the outcome of the accounting framework.

The decision to use any of these approaches in an accounting framework may rest on what kind of analysis is involved. In a situation where the goal is to assess the potential impacts of a specific policy, the approach to establishing a baseline will likely be different than in the case where the goal is to assess the landscape and atmospheric impacts of using biogenic feedstocks for energy over a certain period. While an overarching goal of GHG mitigation is to influence GHG concentrations (UNFCCC, 1994), individual policies are more typically framed in terms of emission *reductions (*or *increases in sequestration)*. For this reason, any GHG mitigation policy affecting terrestrial sequestration or biogenic CO_2 emissions would likely need to estimate future emissions and sequestration levels in scenarios with and without the policy in order to assess its possible impacts. Either the anticipated future or the comparative approach could be effectively employed in such situations. Because both approaches use projections of future emission levels, the uncertainty inherent in those projections would need to be considered and addressed appropriately. In the case of carbon stocks on land, uncertainties are related to modeling and extrapolation, as well as to the potential for unexpected future events, both biophysical and economic.

Specific examples from other policy contexts can help illustrate the differences among these three approaches. Consider a program that seeks to reduce emissions from deforestation by rewarding landowners or countries that reduce deforestation rates compared against a prediction of future deforestation rates without the program (the anticipated future baseline approach). In this situation, the program may still achieve its goals of reducing emissions even though there is a net loss of carbon from the land, and a net increase in atmospheric CO_2, provided that the rate of deforestation and associated losses is lower than historical (expected) rates. In a similar fashion, analyses using a comparative approach might be used to show, for example, the relative emission impacts of a policy designed to encourage renewable electricity relative to fossil electricity.

Conversely, the reference point approach allows for assessment of whether the atmosphere gained or lost CO_2 from a particular region. This approach is useful for situations that do not require an evaluation of the possible impacts of a specific policy or program, but rather seek a measurement of what has or has not occurred on the landscape. Such an approach will implicitly incorporate, for example, historic trends in forest stocks, current forest management conditions, and other demands for biogenic feedstock materials that could influence carbon stock changes. This approach, too, will require addressing uncertainties—for example, uncertainty stemming from data coverage—but such uncertainties differ in nature from those inherent to techniques that use future projections.

E. Other Baseline Considerations

There are other issues that must be considered when establishing a baseline for accounting for biogenic CO_2 emissions from stationary sources. Decisions made on how to address these issues will depend largely on application of a framework to a specific program and policy. These include, but are not limited to exogenous effects on land-based carbon stocks, fuel treatments, and marginal versus average impact accounting.

1. Exogenous Effects on Land-Based Carbon Stocks

Multiple forces will contribute to the terrestrial carbon stocks in a region, many of them unrelated to stationary source demands for feedstocks. These factors range from anthropogenically induced factors such as land-use change (e.g., urbanization) and timber harvest for roundwood, to natural disturbances such as insect infestation, storm damage, drought, and fire. The likelihood of these events may vary over space and time, and they may respond to unexpected factors, such as the introduction of an exotic pest species or market response to global economic conditions. The magnitude of their impact may also vary in unexpected ways, with the result that predicting terrestrial carbon stock change in response to these exogenous events may be difficult and uncertain. An accounting framework that seeks to account for carbon stock changes occurring offsite should nevertheless acknowledge the possibility that these exogenous factors are likely to influence carbon stocks on land and—depending on the policy or program—may potentially attempt to account for these factors.

2. Fuel Treatments

Foresters may prescribe fuel treatments involving the removal of sound live or dead trees to reduce fuel loading, especially in areas where fire exclusion has artificially altered the natural density of forest stands. These treatments can reduce fire severity, thereby reducing the CO_2 emissions associated with wildfire when it does occur (Mitchell et al., 2009; Reinhardt et al. 2010; Reinhardt et al., 2008). While fuel treatments result in an immediate loss of carbon from forests, some researchers have found that recovery can be rapid if large, fire-resistant trees are left on site (Hurteau and North, 2010). Others have reported that at the landscape level, fuel treatments will reduce carbon storage on land because the loss of carbon stocks due to the treatment itself has a larger effect than the reduction in fire severity associated with the treatments (Mitchell et al., 2009). However, because fires are caused by events such as lightning strikes, fuel treatments do not reduce the ultimate risk of fire ignition in forests. As explained by Ryan et al. (2010), "Fuel treatments trade current carbon storage for the potential of avoiding larger carbon losses in wildfire. The carbon savings are highly uncertain."

3. Marginal versus Average Impact Accounting

When multiple stationary sources (such as biomass-fired electric generating units) draw from a single renewable resource (such as the forest biomass on a landscape), the resource will be depleted on individual parcels but can be maintained across the total landscape to ensure continued carbon stocks, and may even experience growth in stocks over time. But when the collective, annual harvest of multiple participants across the total landscape exceeds the annual rate of renewal across that landscape, the resource will be depleted over time. The question may then arise about how to account for the impact from older versus newer users of the resource. Decision makers must consider whether it is appropriate to attribute the resource depletion to only the new feedstock users (who might have entered the market subsequent to the point in time when the resource depletion began), or to attribute the resource depletion and associated biogenic CO_2 emissions proportionally to all of the feedstock users, new and old, who may be drawing from the resource in excess of its rate of replenishment. When making this decision, it would be important to consider whether the stationary sources are responsible in some logical sequence for their individual impact on the remaining annual surplus/deficit or—when deficits occur—whether all users share responsibility, perhaps in proportion to the magnitude of their harvests (e.g., apportioning share of responsibility based on size of entities using the resource).

3.10 Biogenic Feedstock Categorization and Disaggregation

A wide variety of feedstocks result in biogenic CO_2 emissions from stationary sources. These feedstocks differ in physical properties, origin, life cycle, and whether they are deliberately raised as an energy feedstock, are reclaimed wastes from other processes, or are salvaged following extreme events such as hurricanes or insect outbreaks. It may be appropriate for the accounting framework to distinguish among the feedstock types or production systems. For example, annual crops might be accounted for differently than perennial crops, and both might be accounted for differently than wastes (e.g., due to their characteristics annual crops and waste materials may result in more of an adjustment at the stationary source than other feedstocks). Further, a feedstock in continuous supply may be accounted for differently than a feedstock available only occasionally as the result of fire or insect infestation.

There are three broad categories of feedstocks that largely capture all of the sources for biologically based materials that might be used in a stationary source: (1) forest-derived woody biomass, (2) agricultural biomass, and (3) waste materials.

When assessing these feedstocks it is important to consider the key characteristics of feedstock sources that lead to differing effects on the atmosphere, including the following:

- *Transportation, Storage, and Processing Losses*. Steps involved in converting a biogenic feedstock into a bioenergy product may involve losses of the biogenic carbon during storage, transportation, and processing. These feedstock losses vary according to the feedstock type.
- *Land-use changes/Leakage*. The cultivation and use of certain biogenic feedstocks can create market competition that stimulates a shift in use of land for different functions. These land-

use changes can generate emissions that contribute to the net atmospheric impact of using the feedstock at a stationary source.

- *Time Scale over which Sequestration Occurs.* Across certain feedstocks, sequestration of the carbon into the feedstock can occur over a short time (i.e., a year or less), or over a much longer time (i.e., ten to twenty-five to hundreds of years). The time period over which carbon cycles versus the instantaneous release of emissions to the atmosphere from combustion creates a varying element of time for each feedstock type.

- *Baseline Assumptions on "What Would Have Happened Anyway."* These assumptions involve consideration of the end-of-life emissions profile of the feedstock if it was not used at the stationary source. For example, the feedstock can be oxidized and emitted as biogenic carbon to the atmosphere in a reasonably short amount of time or the feedstock can remain as sequestered carbon for some quantifiable period of time. Further, the feedstock could decompose and emit both CO_2 and methane, which has a larger impact on the Earth's radiative balance than CO_2 emitted when the feedstock is used for energy.

A. Forest-Derived Woody Biomass

This feedstock category includes biomass that is derived directly from (U.S.) natural forests and tree plantations,[32] as well as secondary forest-derived biomass from facilities that process forest products such as saw- and pulp mills. Discarded wood products and other wood-derived waste (e.g., construction debris and unwanted pallets) are discussed in the waste materials subsection. To simplify the discussion, woody biomass can be further categorized based on the alternative fates of the material removed for energy production: (1) forest and mill residue, (2) non-merchantable forest biomass, (3) timber roundwood harvest in a commercial market area, and (4) roundwood harvest from a dedicated source.

Forest and Mill Residue. The process of harvesting timber and processing roundwood at mills involves a substantial amount of byproducts (DOE, 2004). Forest residues are biomass derived from "residue, including treetops, non-merchantable sections of the stem, branches, and bark, left on the ground after logging or accumulating as a result of a storm, fire, delimbing, or other similar disturbance" (EPA, 2009b). This material is often left on site after a harvesting operation and eventually will be burned or will decompose, releasing carbon into the atmosphere and into organic matter on the forest floor and soil (Evans and Ducey, 2010). These residues can be assumed to be a byproduct in most cases (i.e., a biomass market did not trigger the harvest operation in the first case).

Mill residues are secondary forest-derived biomass procured from a wood processing facility such as a saw- or pulp mill. Sources from sawmills typically include peeler shavings, sawdust, and bark, while product streams from pulp mills also include lignin and other wood components, black liquor, or liquid fuels such as cellulosic ethanol. Most of this material is currently burned for energy or heat at the facilities; some may be sold for mulch or for processing into pulp (Johnson, 2001).

Non-Merchantable Forest Biomass. There are occasions when woody biomass may be removed from a forest without affecting markets for commercial roundwood. In such cases, leakage effects are minimal or non-existent, and the alternate fate of this biomass would be loss to management-

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[32] Short rotation woody crops systems with typical rotations of less than 15 years are not covered here but discussed in the "agricultural products" section.

induced prescribed fire, wildfire, or decomposition. Examples include harvest of pulp-quality biomass for energy purposes in a region where a pulp market is absent, pre-commercial thinning of trees that are not of a merchantable size, low-grade biomass harvests in large areas of forest damaged from insects (e.g., beetle-killed timber), hurricanes, or wildfire. In most cases, trees damaged in this form have no market value except for biomass due to the nature of the damage. Removal of dead trees can decrease the severity of wildfires, and enhance conditions for regeneration. Biomass from salvage operations is unique in that the harvest operation was triggered by an event beyond the control of the forest manager, potentially reducing total live tree carbon stock of a forest substantially.

Timber Roundwood that is Not Used for Energy. In many forest harvest operations, the commercial timber is separated into saw timber and pulpwood at the harvest or mill site, since these products may differ significantly in sale value and often go to different mills for processing. When a market for energy feedstocks is available, feedstock prices have historically been lower than those of saw timber or pulpwood, so this results in a three-way separation of the material. Where this is the case, and the timber and pulpwood do not enter the bioenergy facility, they are not included in the facility's carbon accounting. Similarly, when the bioenergy stationary source is part of a saw or pulp mill, the carbon that goes out of the mill in products is not counted in the mill's direct emissions.

Timber Roundwood Harvest in a Commercial Market Area. This type of woody biomass entails the harvest of trees of commercial size, species, and quality from a forest in an area with commercial markets. This includes forest management treatments, such as thinnings, that remove trees of merchantable size. The difference in this case from the previous cases is that the removal of biomass for energy production is in competition with removals for other products. Thus it can potentially create leakage issues. It can also raise the issue of "what would have happened anyway." Where wood goes into commercial use for paper or solid wood products, a portion of the carbon content remains sequestered for a period of time (Heath and Skog, 2004). Using methods and tables published by the USDA Forest Service (USFS), the amount of carbon that remains sequestered in wood products for long periods of time (i.e., 100 years) can be estimated for different types of wood, wood products, and geographic regions (Skog and Nicholson, 2000). Commercial wood that is diverted into energy use and processed immediately shortens this decomposition cycle.

Roundwood Harvest from a Dedicated Source. This type of woody biomass feedstock includes roundwood from a landscape that is dedicated as an energy source. An example might be a company that owns and manages forest plantations, specifically for the production of woody biomass for energy use. A key consideration relative to the harvest of commercial roundwood is the likelihood that current forest growth will recapture the carbon from energy emissions. Forest ownerships may use methods such as a continuous forest inventory or forest certification to demonstrate that ongoing carbon stocks in the forest are maintained or increased under the management scheme.

1. Possible Data Sources for Forest-Derived Woody Biomass

The USFS maintains the Forest Inventory Analysis (FIA) database, which reports information on the status and trends of America's forests through sampling, surveys, and assessments (USDA Forest Service, 2011b). The database includes data that summarize the acreage of standing forest, as well as tree mortality, removals, and net growth of forests. These measured plot data can be aggregated or disaggregated to generate estimates at multiple spatial scales, and include information on land ownership, physiographic factors, forest type, and other forest characteristics. Biomass equations can then be applied to get the total biomass from these FIA data results.

Besides the basic forest inventory, FIA also conducts Timber Products Output studies to estimate the industrial and non-industrial uses of roundwood (USDA Forest Service, 2011c). To estimate the industrial uses, all primary wood-using mills in a state are surveyed to determine location, size, and types of the mills and the volume received. In addition, the volume, type, and disposition of the wood residues generated during processing are included.

The database also has the capability to project the future state of the forest based on various inputs and scenarios (USDA Forest Service, 2011a). Data are collected annually and state reports are produced every five years, with one-fifth of the plots re-measured each year to create a complete re-measurement in five years.

2. *Implications for Forest-Derived Woody Biomass*

This subsection uses examples to illustrate the variation in different forest-derived woody biomass types based on the issues discussed earlier related to developing an accounting framework for biogenic CO_2 emissions from stationary sources.

Emissions from Transportation, Storage and Processing. Forest-derived woody biomass generally experiences fewer losses during transportation and storage than agricultural biomass. However, within forest-derived woody biomass types, residues and fuel treatments are more likely to experience feedstock losses during haulage and handling than roundwood because of the smaller size of the feedstock pieces. Processing losses of forest-derived biomass are minimal as these can usually be combusted without any pre-processing.

Land-Use Changes/Leakage. Forest-derived biomass can have several markets competing for the same raw product. For instance, pulp and biomass-to-energy markets can compete for the same tree sections. Increasing biomass production for energy in one location can therefore result in leakage in another area (i.e., indirect land-use change), as it creates a geographical shift of the pulpwood market when assuming a constant pulp demand. Therefore, potential leakage should be considered for those biomass feedstocks that are currently marketed elsewhere as a commodity.

The type of harvest operation (e.g., whole tree versus non-whole tree harvest), stand and timber structure, and soil conditions play significant roles in the abundance and merchantability of forest residues. For instance, hardwoods in general yield higher percentages in non-timber biomass than softwoods. If soils are wet, this material may be used to stabilize skid trails and there will be no surplus for feedstock supply. Extracting biomass for energy production often requires the simultaneous harvest of more valuable wood (timber, pulpwood) quantities to justify the cost of collecting the material, subsequently increasing pressure to expand the area or intensity of harvest operations. Therefore, environmentally sensitive logging methods make a significant difference in the overall impact and availability of this resource.

Most woody biomass residues from wood-using mills are currently used or sold for other products. For example, sawdust and chips from sawmills are often sold to pulp mills. Bark, slabs, edges, and other material may be burned on-site at the mills for heat and energy production. Thus, when mill residues are diverted into dedicated energy facilities, it may be an indication that leakage effects are possible (i.e., if sawdust goes to a biomass energy facility rather than a pulp mill, the pulp mill will need to make up the shortfall, possibly by increasing pulpwood harvests). Carbon dioxide emissions from biomass harvested during salvage operations and pre-commercial thinnings would likely be emitted anyway if the material were not used as a feedstock, and thus leakage analysis plays a minor role in accounting for these materials.

If biomass sold to the energy market could have also qualified for the timber or pulp market, its removal is in competition with removals for other products. If increased demand for woody biomass leads to direct land-use or land use management change, this should be accounted for. Additionally, there are several indirect land-use change implications for using forest-derived biomass as a feedstock. Using wood chips as biomass could lead to an increase in production and import of wood chips abroad, which could result in international land-use change.

Temporal Scale. Forest-derived woody biomass varies in the time it takes to sequester carbon and release it back to the atmosphere. Feedstock types such as harvested round wood, if used for industrial purposes other than energy, could lead to long-term carbon sequestration: for example, if the wood was used for furniture or pulp and paper,[33] its carbon would be sequestered for longer than if it is burned immediately for energy purposes. Re-growth in a sustainably managed forest would result in sequestration on a time scale concurrent with harvest removals. If left in the forest, harvest residue may either be burned to facilitate regeneration or left to decay over a period that can range from days to years, depending on the size and nature of the woody material and the environment in which it is grown. Non-merchantable large woody material decays slowly in the forest and its carbon content in the forest can be estimated from sampling surveys.

Baseline Assumptions about What Would Have Happened Anyway. The various forest-derived woody feedstock types have different impacts on the atmosphere with respect to their non-energy use. If harvest residue is not removed for bioenergy, it would have decayed or been burned in the forest. Under current biomass market prices in most regions, the procurement of residue does not trigger the harvest operation. For timber used for commercial purposes, it is important from a carbon-accounting perspective to determine whether these biomass removals are being replaced by ongoing forest growth. In a scenario where the marketing of residues, or other currently un-merchantable tree sections for energy use becomes profitable, these assumptions would have to be revised.

B. Agricultural Biomass

Agricultural feedstocks can be widely categorized into conventional crops, energy crops, crop residues, and processing byproducts. Each of these feedstocks is discussed below.

Conventional Crops. Conventional crops like corn, sorghum, and hay can be converted at stationary sources into conventional starch-based fuels, electricity (grasses only), biodiesel, and cellulosic fuels. For these crops the feedstock growth location is the farm, and may contribute to indirect land-use change if the traditional harvested biomass (e.g., grain) is diverted to bioenergy production (as discussed below). Crops for which only the processing byproducts from a multi-product processing activity (e.g., soybean oil, and rice hulls) are covered under the processing byproducts subsection below. There are multiple downstream products derived from conventional crops that should be considered in an accounting framework. For example, use of grass for cellulosic ethanol purposes potentially yields both cellulose-based fuels and lignin that in turn are combusted elsewhere.

Energy crops. Energy crops like switchgrass, poplar, willow, miscanthus, energy sorghum, and others can be converted at stationary sources into such products as electricity, cellulosic fuels, and

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[33] The length of time for which carbon is sequestered also varies according to the lifespan of different wood products. Products such as furniture are likely to store carbon for much longer than those like pulp and paper. The sequestration time also depends on the end-of-life of these products; that is, if they are combusted for heat or energy after use—instant emissions—versus if they are stored in a landfill—where some emissions may occur due to decay but most of the carbon is considered to be stored.

biodiesel. For these crops, the feedstock location is the farm and land-use change is generally involved because existing forestlands, croplands, or grasslands are usually converted to grow these feedstocks. Indirect land-use change can also occur, as discussed below. There are multiple products created by processing these crops. For example, use of these crops for cellulosic ethanol purposes potentially yields cellulose-based fuels and lignin that can be burned elsewhere. Biogenic CO_2 accounting for these crops requires consideration of the carbon that remains in post-combustion residual products (e.g., from incomplete combustion) or biogenic CO_2 emissions that are captured and stored instead of being released into the atmosphere when the feedstock is combusted or processed (e.g., biochar after pyrolysis).

Crop residues. Residues in the form of stalks and straw from crops like corn and wheat can be converted or combusted at stationary sources, yielding products like electricity, cellulosic fuels, and biodiesel. The feedstock location is the farm for these feedstocks, and no land-use change will typically be included. However, due to management changes, there may be a soil carbon impact.

Processing byproducts. Processing byproducts in the form of vegetable oil, rice hulls, tallow, animal fats, etc. can be converted at stationary sources into products like biodiesel, cellulosic fuels, and electricity. Under this use scenario, the feedstock location is the processing plant. Carbon that remains in post-combustion residual products also needs to be accounted for, as ash may be left after electricity generation or char after pyrolysis.

1. Possible Data Sources for Agricultural Biomass

USDA National Agricultural Statistics Service (NASS) *Agricultural Statistics* (USDA, 2009) is an annual publication that provides data for the acreage of crops that are planted each year. These data have been informative for GHG emission inventories (see Inventory of U.S. Greenhouse Gas Emissions and Sinks, EPA, 2011a). However, these data do not break down the uses for those crops (e.g., food for human consumption, food for animal consumption, biofuels, and biomass). While the relevant contributions of any land-use change from increased biomass production are not explicit in this data set, it might be possible to identify trends in regions where there has been known penetration of biomass-using facilities. In addition, USDA-NASS has developed remote sensing-based data, referred to as Cropland Data Layers, that provide spatial maps of the cropland cover throughout the conterminous United States, which may augment the traditional commodity statistics.

2. Implications for Agricultural Biomass

This subsection uses examples to illustrate the variation in different agricultural biomass types based on the issues discussed earlier related to developing an accounting framework for biogenic CO_2 emissions from stationary sources.

Emissions from Transportation, Storage, and Processing. Agricultural feedstocks generally need to be processed before they can be used for energy. Additionally, because of their seasonal nature, agricultural biomass needs to be stored to provide a year-round supply of energy. Thus, agricultural biomass may experience more feedstock losses than forest biomass. Accounting for agricultural biomass such as residues and byproducts should cover any losses in hauling, storage, and material handling. While these losses may be small compared with feedstock use (about 5 percent), these losses in the supply chain are required to link what is being used at the stationary source to what is grown at the feedstock growth location.

Land-Use Changes/Leakage. There can be significant indirect land-use change effects if the harvesting/production of feedstocks affects commodity markets and thus leads to changes in production that alter sequestration and leakage elsewhere (Murray et al., 2004; Searchinger et al., 2009). This effect can be significant for energy crops. For example, if cropland is converted to a short-rotation woody crop for energy production, displacing corn from the marketplace, the corn can be replaced by production elsewhere. There is potential significant leakage elsewhere, particularly if forested or grassed lands are brought into crops. Typically, there are no land-use change effects from removal of agricultural residues, waste, and byproducts. However, land-use management changes can affect soil GHG fluxes.

Temporal Scale. Growth of conventional and energy crops generally occurs at time scales of a year or a few years, with short-rotation woody crops having the longest growth cycle in this category. Even in those cases a stationary source would need an inventory of feedstocks of different ages so that growth across all the stationary source feedstock would offset current combustion. Thus agricultural feedstocks generally sequester and are oxidized at the same time scales. Time scale is not a relevant consideration for processing byproducts and residues.

Baseline Assumptions on What Would Have Happened Anyway. If agricultural biomass was not used for bioenergy, there would be no dedicated planting of energy crops, and conventional crops would be used for other purposes, such as food, or animal feed and fiber. Agricultural residues, like forest residues, would decay and make small contributions to soil carbon if they are not removed for stationary source use. Removing residues may increase the return of carbon to the atmosphere from the residues in the short term and reduce the amount of carbon stored in the soils over a longer term.

C. Waste Materials

Waste materials include municipal solid waste, construction and demolition waste, industrial waste, animal wastes, manure, tire-derived wastes (TDW), and wastewater. Each of these is elaborated on below.

Municipal solid waste (MSW). MSW includes waste generated by residential, commercial, and institutional entities. It contains a variety of biogenic materials the composition of which varies by region, season, and long-term trends in waste generation. The average national composition of MSW in 2008 is estimated by EPA (2009b) in Municipal Solid Waste Generation, Recycling, and Disposal in the United States Detailed Tables and Figures for 2008.[34] The primary biogenic fractions of MSW include paper, food waste, yard waste, wood, diapers, natural fiber textiles, and natural rubber. MSW is defined slightly differently by different states. Both the overall carbon content and the ratio of fossil carbon to biogenic carbon of MSW vary widely. MSW is typically treated through landfilling or combustion. MSW that is not recycled is typically treated through landfilling or combustion. Over half of CH4 generated in MSW U.S. landfills is captured for combustion (EPA, 2011a).

Construction &Demolition (C&D) Waste. C&D waste generally consists of the debris generated during the construction, renovation, and demolition of buildings, roads, and bridges. In terms of composition, there are limited data to characterize C&D waste but it typically consists of bulky, heavy materials, such as concrete, asphalt, wood, metals, glass, roofing, and salvaged building components. The most recent EPA characterization of C&D waste was completed in 1998.[35] The

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[34] http://www.epa.gov/epawaste/nonhaz/municipal/pubs/msw2009-fs.pdf.

[35] http://www.epa.gov/epawaste/hazard/generation/sqg/c&d-rpt.pdf.

primary biogenic feedstock available from C&D waste is wood, and a smaller fraction of paper from drywall and packaging. Similar to MSW, there is variability between states in how C&D waste is characterized.

Industrial Waste. Industrial waste is often a significant portion of solid waste, even in small cities and suburbs. There are little data available for characterizing industrial waste. Industrial waste will include the main biogenic materials of paper, wood, food, natural fiber textiles, and natural rubber. Industrial waste is typically treated through landfilling.

Livestock wastes. Livestock manure, litter, and manure wastewater are typically treated in a manure management system that stabilizes and/or stores wastes in one or more of the following system components: uncovered anaerobic lagoons, liquid/slurry systems with and without crust covers (including but not limited to ponds and tanks), storage pits, digesters, solid manure storage, dry lots (including feedlots), high-rise houses for poultry production (poultry without litter), poultry production with litter, deep bedding systems for cattle and swine, manure composting, and aerobic treatment units. Decomposition of the manure can occur through anaerobic or aerobic decomposition. Some manure management systems combust CH_4 from anaerobic treatment.

Tire-Derived Wastes (TDW). Scrap tires have multiple uses, including use as a feedstock for TDW. Tires contain a biogenic component in the form of natural rubber or biomass, which comprises approximately 20 percent of the tire based on information collected from the Rubber Manufacturers Association (EPA, 2010e). TDW is typically treated through combustion. TDW is often co-fired with other fuels, but may also be the primary fuel.

Wastewater. Wastewater is typically treated through processes that treat or remove pollutants and contaminants, such as soluble organic matter, suspended solids, pathogenic organisms, and chemical contaminants, from wastewater prior to its reuse or discharge from the facility. Sources include municipal and industrial wastewater treatment facilities. Some wastewater treatment facilities combust CH_4 from anaerobic treatment.

1. Possible Data Sources for Waste Materials

EPA's AgSTAR program keeps data on anaerobic digesters operating at U.S. commercial livestock farms (e.g., dairy, swine, poultry, and beef projects).

The Rubber Manufacturers Association periodically compiles data on the use of TDW as a feedstock in U.S. markets, most recently in 2007.

The U.S. Environmental Protection Agency's Landfill Methane Outreach Program is a voluntary assistance program that helps to reduce methane emissions from landfills by encouraging the recovery and beneficial use of landfill gas as an energy resource. This program has an extensive publicly accessible database.

The Inventory of U.S. Greenhouse Gas Emissions and Sinks (EPA, 2011a) adheres to both: (1) a comprehensive and detailed set of methodologies for estimating sources and sinks of anthropogenic greenhouse gases, and (2) a common and consistent mechanism that enables Parties to the UNFCCC to compare the relative contribution of different emission sources and greenhouse gases to climate change. The Inventory report has a section and related data on waste management and treatment activities.

EPA's *Municipal Solid Waste (MSW) in the United States: Facts and Figures* has data from 2009 on MSWs, landfills, related energy recovery, combustion and more.

2. *Implications for Waste Materials*

Considering the broad range of waste management systems, and the different types of biogenic and anthropogenic emissions of those systems, there are a number of potential ways waste materials could be treated in an accounting framework.

A critical difference between waste and other biologically based material is related to the connection to the land providing the material. The biologically based material in waste is removed from land for other economic purposes (e.g., for manufacture of consumer and industrial products such as newspaper, food, and construction). Given that the treatment of waste itself does not drive the management of the growth and harvesting of biomass, it is more difficult to quantify a connection between the consumption of waste at stationary sources and the positive or negative CO_2 impact on the atmosphere.

The treatment of waste at a waste management system emits carbon as CO_2 that would have otherwise been returned to the atmosphere from natural decay of waste, regardless of the management or status of the land providing the biological material. The human management of the waste materials affects only the timing or location of these CO_2 emissions.

In addition to biogenic CO_2 emissions, waste management systems can also emit large quantities of CH_4. Methodologies for estimating and accounting for CH_4 from waste management are available and widely used in many GHG accounting programs. Many waste systems already account for CH_4 using methodologies from the EPA Greenhouse Gas Reporting Program (GHGRP). The decision to consider avoided methane emissions in an analysis should be made in the context of the type of baseline that is most appropriate given the policy context. In a full lifecycle analysis, the industries producing the waste could calculate the full greenhouse gas impacts of their supply chains.

This accounting framework considers the comparison of CO_2 emissions from waste management sources to CO_2 emissions from a baseline of no waste management. An alternative accounting framework could consider the net biogenic carbon dioxide equivalent (CO_2e) emissions from a waste management system, compared with the biogenic CO_2e emissions implications associated with decomposition of the same waste in other types of managed systems. For example, an assessment of waste materials diverted from a landfill to an incinerator for energy production could consider the biogenic CO_2 emissions that occur at one point in time (at the incinerator) against the avoided CO_2 and CH_4 generated over decades through decomposition in the landfill, and also avoided carbon storage in the landfill (IPCC, 2006c; EPA, 2010a; EPA 2011b), or it could consider the biogenic CO_2 emissions against the CO_2 that would be emitted through the natural decay of the original biomass.

4 Accounting Framework: General Description

Section 4 presents the decisions EPA has made on the technical and methodological issues presented in Section 3 to develop an accounting framework for biogenic CO_2 emissions from stationary sources and the rationale for those decisions. Then, Section 5 presents the detailed technical equation for the accounting framework.

The remainder of this section is organized as follows:

- Gases to Include
- Direct Emissions
- Feedstock Losses During Transportation and Storage
- Carbon Contained in Products and Byproducts
- Feedstock Growth: Emissions and Sequestration on Land
- Waste Materials
- Land-Use and Management Changes
- Temporal Scale
- Spatial Scale
- Baselines
- Biogenic Feedstock Categorization and Disaggregation

4.1 Gases to Include

This accounting framework focuses on biogenic CO_2 emissions because, as explained in Section 2, it is a critical component of the carbon cycle.

4.2 Direct Emissions

This accounting framework includes the direct emissions from a biologically based feedstock when it is transformed at a stationary source to CO_2 via combustion, decomposition, or another process such as fermentation. As explained in Section 3, inclusion of a stationary source's direct emissions is a critical component of a framework to adjust the onsite biogenic emissions total. These CO_2 emissions can be estimated at the stationary source as: (1) direct emissions from the stack or vent (via monitoring technology such as continuous emissions monitoring system, for example), (2) a function of feedstock produced, or (3) a function of feedstock received at the stationary source.

4.3 Feedstock Losses During Transportation and Storage

This accounting framework includes a term that can be used to account for the potential difference in carbon content when feedstocks are measured at the feedstock production site versus when they are measured at the stationary source. As discussed in Section 3, it is important to account for this carbon—contained in feedstocks produced for stationary sources but lost before use—because accounting for this loss, where it occurs, completes the mass balance between the stationary source and the land where the feedstock is produced. In the framework, to adjust a stationary source's total onsite biogenic emissions, the measurement of tonnage fed into the stationary source does not reflect the amount actually grown on the landscape. And since the framework seeks to link the emissions from the source with the sequestration that occurs offsite, an accurate estimate of the feedstock that is produced as well as the feedstock that is used is important.

4.4 Carbon Contained in Products and Byproducts

This accounting framework accounts for products and byproducts that may divert a portion of the carbon in the input feedstocks used at the stationary source. It creates a mass balance for the feedstocks used, such that the carbon delivered in feedstock is equivalent to the carbon released from the source via direct emissions and the carbon stored in two kinds of products: commercial products generated via a processing step (e.g., lignin, ethanol), and the carbon stored as a byproduct of combustion or other processing (e.g., CCS, ash). It includes separate terms to account for these instances of carbon storage in products and byproducts. It is important to include terms for these products and byproducts in the accounting framework to ensure the mass balance reflects the quantity of carbon emitted by the stationary source versus the quantity stored in products.

As described in Section 3, a variety of products may be produced at stationary sources, including processing residuals (e.g., unoxidized carbon in ash), fuels that will be oxidized later (e.g., ethanol), and durable products that may or may not be converted to CO_2 over longer timeframes (e.g., lumber). This framework acknowledges but does not attribute emissions to the stationary source that arise from products and byproducts that are created, but not used, at a stationary source.

The fate of byproducts that sequester carbon can be attributed to the stationary source (such as fly ash) in cases when the stationary source does not sell them, but this assumption can be modified per the needs or design of a specific application of this framework. Also, if a stationary source employs CCS technologies, it could be possible to include the effect of biogenic CO_2 emissions stored by such technologies within this framework.

4.5 Feedstock Growth: Emissions and Sequestration on Land

This accounting framework includes the biogenic CO_2 emissions and sequestration in both the growth of the feedstock itself and the additional emissions or sequestration on land associated with feedstock production (e.g., changes in soil carbon and standing vegetation). In order to account for these emissions and sequestration, the framework quantifies the changes in carbon stocks on the landscape where the biogenic feedstock is produced or collected. These are important components of the accounting framework because, as explained in Section 3, the emissions and sequestration occurring on the land are integral to the carbon cycle associated with the production and use of biologically based feedstocks.

Specifically, the quantification of these terms varies slightly according to the feedstock category, though all feedstocks use the same equation.

- For **agricultural biomass feedstocks**, the framework can acknowledge that these are typically grown and harvested so that there is likely no difference in the amount of carbon in the atmosphere at the beginning and the end of the year. It also involves consideration of the impacts on soil as well as land-use changes that may or may not affect the outcome of the net biogenic CO_2 emissions calculation.

- For **forest-derived woody biomass feedstocks** (or perennial agricultural energy crops such as switchgrass or short-rotation woody crops), the framework relies on the fact that—when harvest for bioenergy is balanced by sequestration in biogenic feedstock growth at the landscape scale—the net change in forest carbon stocks from year to year will be zero. When these elements are not in balance, the framework calculates the net impact of sequestration versus emissions. This calculation includes comparison of the net carbon stock status (and thus the assessment of the net impact of biogenic feedstock harvest for use as bioenergy) at a regional scale that occurs retrospectively, over a series of years in the recent past, via an inventory-based assessment of standing stocks (e.g., FIA) at some spatial scale. This type of baseline comparison is explained further in Sections 3.9 and 4.9.

Developing the accounting framework in a way that is flexible enough to treat these feedstock categories differently recognizes that feedstocks differ from one another in terms of their growth characteristics and sequestration patterns. For example, depending on the program or policy, the framework could be easily adapted to allow a stationary source to adjust its biogenic CO_2 emissions from use of agricultural biomass in a straightforward manner without significant burden or data, given the typical growth and harvest pattern of such feedstocks.

4.6 Waste Materials

As discussed in Section 3, waste materials such as municipal solid waste are typically sent to landfills, wastewater treatment systems, manure management systems, etc. where they decompose through aerobic and anaerobic processes, or to waste incinerators for combustion.

For the purpose of this report, CO_2 emitted from the treatment of waste at a waste management system would have otherwise been returned to the atmosphere from natural decay of waste, regardless of the management or status of the land providing the biological material. The human management of the waste materials affects only the timing or location of these CO_2 emissions.

Therefore, for this accounting framework, BAF is considered to equal 0 for biogenic CO_2 released from waste decay at waste management systems, waste combustion at waste incinerators, or combustion of captured waste-derived CH_4. If any portion of materials entering a waste incinerator is harvested specifically for the purpose of energy production at that incinerator, biogenic CO_2 emissions from that material would need to be accounted according to the framework calculations provided in Section 5. In a full lifecycle analysis, the industries producing the waste could calculate the full GHG impacts of their supply chains, but such an analysis is beyond the scope of this study.

4.7 Land-Use and Management Changes

A. Direct Land-Use and Management Changes

This accounting framework includes the biogenic CO_2 emissions that occur when direct land use or management is changed to produce a biologically based feedstock for use by a stationary source. Depending on the nature and quantity of land that is converted from one land-use type to another, the implications for the change in carbon stocks on land could be fairly minimal to quite large. For example, changes that result from shorter harvest cycles for forests and the impacts of different land uses and management regimes on carbon pools such as live biomass, dead biomass, and soil carbon are reflected in this framework.

B. Indirect Land-Use Change and Leakage

This framework recognizes the importance of indirect land-use change and leakage in accounting for biogenic CO_2 emissions from stationary sources, as emissions occurring outside the feedstock production system could be significant. As discussed in Section 3, new biogenic feedstock can have impacts on the market for and availability of feedstocks, resulting in direct and indirect land-use change.

However, no specific quantification methodology for leakage is established in this framework because assessing leakage requires policy- and program-specific details that are beyond the scope of this report. The specific policy context where this accounting framework is applied may also factor into whether and how leakage is addressed. The decision to include a quantification of leakage in the context of a specific policy application should be based on: (1) a qualitative assessment of the likelihood of significant leakage occurring, and (2) an assessment of the availability of data and appropriate modeling approaches. If it is determined in a stationary source-specific setting that significant emissions are caused outside the biogenic feedstock supply chain for the stationary source and are reasonably attributable to biogenic feedstock production and use, and if data and modeling capabilities are available, these emissions should be quantified and included in the calculation of net CO_2 atmospheric impact of using biogenic feedstock at a stationary source.

C. Other Land-Use Considerations

As discussed in Section 3, the concept of "carbon debt" is important to consider when evaluating land-use and land-use management changes (direct and indirect) and the ensuing impacts on landscape carbon stocks. This framework seeks to quantify the annualized net CO_2 emissions associated with using biogenic feedstocks in stationary sources at the regional scale. This is done by analyzing landscape-level changes in carbon stocks, consistent with the way carbon debt is described by Fargione et al. (2008) and Zanchi et al. (2010). In the framework, the "debt" is factored into annualized net emissions.

While the accounting framework addresses the overall issue of carbon debt via its emphasis on tracking landscape-level carbon stocks as they vary with bioenergy harvest, it does not emphasize specific analysis of the time required to repay the carbon debt values. Rather, it divides by the number of years that the stationary source is assumed to be in operation (generally 30) to annualize the debt.

4.8 Temporal and Spatial Scale

This accounting framework applies an annual or annualized time step for all terms, including direct emissions, sequestration in feedstock growth, and sequestration or emissions changes in land under production. However, data may not be available annually for all of these components for all feedstocks. Where annual data are not available, the framework is flexible, and varies depending primarily on the dataset available for the feedstock involved. The data can be averaged over multiple years in instances where data are unavailable at annual timesteps, or in cases where too much variability is present in the data. For example, for forest-derived feedstocks the framework uses a moving average of historical data to develop the estimate of feedstock growth and regional carbon stocks.[36]

This accounting framework uses a regional scale to reflect the important distinctions between regional drivers of changes in land-based carbon stocks and resource supply and demand that could

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[36] Using this moving average approach, assuming that 5 years' worth of data are available at a given time, forest carbon stocks in 2010 might be assessed using the average of data collected from 2006–2010, carbon stocks in 2011 might be assessed using data from 2007–2011, carbon stocks in 2012 might be assessed using data from 2008–2012, and so on. In this way the potential effects of large variations in carbon stocks over time are smoothed, and annual updates can be made based on previous years' data. The number of years captured in the moving average can vary depending on data availability and feedstock characteristics.

be masked at the national level.[37] The balance between spatial and temporal scales is important: the spatial scale of accounting must be large enough that accurate data are available, but small enough to capture important regional characteristics such as growth rates and variation in market demand for feedstocks. Similarly, data must be available at the temporal scale of interest, and the time step must be practical and consistent with feedstock growth patterns. In this framework, accounting for net biogenic CO_2 emissions that cover both a small spatial scale and a short period of time would not be tenable, because it would not allow for the important land-based changes in carbon stocks that do occur over longer timeframes and larger spatial scales.

Also, this accounting framework acknowledges the significance of but does not include assessment of international biologically based feedstock production and the role of imports and exports. Crafting a means to account for these effects would be a policy decision as to how to address this important element depending on particular policy or program requirements and objectives.

4.9 Defining Baselines

A. Reference Point Baseline

This accounting framework uses a reference point baseline for a particular region. This type of baseline was selected because, in developing a framework for a stationary source to adjust its total onsite biogenic emissions, answering the question "Is there more or less carbon stored in the system (the stationary source and its feedstock-supply source) at the end of an assessment period than there was at the beginning?" is a straightforward way to assess an individual stationary source's emissions using existing data.

The application of this type of approach means that, in the case of forest-derived woody biomass, there would be an assessment of whether over the previous five years (or some appropriate window of time) the forest carbon stock level in a source region was steady or increasing, or whether the carbon stock was decreasing. If carbon stocks were historically constant or increasing and continue to do so, then the reference point baseline approach would show that the biogenic feedstock source region—and the associated use in the stationary source itself—is not contributing to an increase in net CO_2 concentrations, and therefore stationary source emissions of CO_2 from consumption of feedstocks from this region are also not contributing to an increase in net CO_2 concentrations. Conversely, if carbon stocks were decreasing from the reference point baseline, then the conclusion is that the source region contributed to an increase in net CO_2 concentrations, and therefore stationary source emissions of CO_2 from consumption of feedstocks in this region also contribute. The magnitude of this contribution depends on the amount of carbon lost from the region, and other carbon losses, e.g., from transport and potentially leakage.

As mentioned above, this type of baseline allows for any assessment of biogenic CO_2 emissions impacts from an individual source at a particular point in time. If the framework were adapted to assess a particular policy or to compare the use of biologically based feedstocks to fossil fuel feedstocks, then another baseline approach may be more appropriate. The three baseline approaches that have been used in similar analyses are discussed in more detail in Section 3.

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[37] In this framework, the exact size of a region is not prescribed. Specific regions would be defined as a matter of policy, but the appropriate size and regional boundaries could depend on multiple factors, including but not limited to economic and market characteristics, biophysical characteristics, and data availability.

B. Other Baseline Consideration

The other baseline issues considered when developing this accounting framework include exogenous effects on land-based carbon stocks, fuel treatments, and marginal versus average impact accounting. Specific decisions made about how to address these issues will largely depend on application of the framework to a specific program and policy. In the framework presented here, these issues are treated as follows:

1. Exogenous Effects on Land-Based Carbon Stocks

As described above, this accounting framework in the forestry case uses the most recent five years' worth of data on land-based carbon stocks to define the current carbon stock value, which is then used as the reference point baseline. If carbon stocks remain constant or increase above this value, then the framework finds that the use of biogenic feedstocks does not have a net impact on the atmosphere; if carbon stocks dip below this value, then the framework finds that the use of biogenic feedstocks is probably affecting the atmosphere. This is a simplifying assumption, however, because other significant factors—unrelated to the production of biogenic feedstocks—may influence changes in land-based carbon stocks. These factors range from anthropogenically induced factors such as land-use change (e.g., urbanization) and timber harvest for roundwood, forest management decisions that might increase or decrease carbon stocks in a given area, to natural disturbances such as insect infestation, storm damage, drought, and fire. As long as carbon stocks on land are increasing, this contribution of other factors does not change the methodological result because, in the aggregate, depletion of carbon stocks caused by all other factors, including harvest of biogenic feedstocks for use in stationary sources, is balanced by sequestration.

When carbon stocks are declining, however, understanding attribution is more important. Arguably, producers and consumers of a biogenic feedstock should not bear responsibility for declines in carbon stocks if other factors are the primary drivers of the decline. At the same time, however, attribution of changes in land-based carbon stocks across a landscape is difficult, as evidenced by the difficulty faced by the IPCC in its ongoing work related to "factoring out" natural and anthropogenic influences on land-based carbon stocks. Ultimately, the decision about how to handle attribution in situations where carbon stocks are declining is critical but not resolved within this framework. In a situation where carbon stocks are declining in a region at a significant rate, it is nonetheless intuitive to conclude that even with other factors involved, use of biogenic feedstocks at stationary sources plays a role in this decline and therefore is likely contributing to an increase in atmospheric CO_2 concentrations.

Multiple options exist for policymakers as they work to resolve this issue. For example, the baseline assessment of carbon stocks could be restricted to just the "working forest" in order to minimize the effect of land-use change on the regional estimate of carbon stocks. It may be appropriate to do nothing, or to take a region-by-region approach, as carbon stocks in most regions of the country are increasing even with the exogenous influences described here. Alternatively, a modeling approach could be used to "factor out" the various natural and anthropogenic influences on land-based carbon stocks. Such a modeling approach would need to be developed and applied for this purpose.

2. Fuel Treatments

This accounting framework does not include a separate feedstock category for material removed during fuel treatments. This is because: (1) as with any other harvest, the treatment itself reduces carbon storage, and (2) the net benefit of the treatment itself is uncertain, given the many factors that influence fire risk, fire severity, and forest recovery. It is important to note, however, that the net effect of any policy to reduce fuel loading and enhance forest carbon storage will be reflected in the five-year retrospective analysis of carbon stocks on the landscape. If the policy performs as intended, the increase in forest carbon stocks will be reflected in subsequent years' analyses of standing stocks.

3. Marginal versus Average Impact Accounting

As highlighted in Section 3, in forestry cases where carbon stocks are declining, attributing responsibility for this decline across existing and new feedstock users is an important decision as it can ultimately affect the results of the framework application. This decision may need to vary according to specific policy or program goals. Therefore, the accounting framework in this report does not make a determination on this issue but rather highlights the considerations related to this issue for any future program and policy application.

Specifically, if accounting is conducted using the marginal accounting method, and a new stationary source will cause carbon stocks to dip below the reference point baseline, then all of the emissions associated with the dip in carbon stocks below the reference point are attributed to the new stationary source. If accounting is conducted using the average accounting method, and a stationary source or a group of stationary sources cause the carbon stocks in the region to dip below the reference point baseline, then the responsibility for the decline in carbon stocks associated with the bioenergy harvest is distributed proportionally to all of the stationary sources that are drawing from the feedstock in that region. The difference between results generated using each of these accounting methods is illustrated in the appendix (Case Studies 1 and 2).

4.10 Biogenic Feedstock Categorization and Disaggregation

This accounting framework includes three biologically based feedstock categories that should be assessed at the regional level: (1) forest-derived woody biomass, (2) agricultural biomass, and (3) waste materials. The framework uses these categories because they are large enough to capture the important differences among feedstocks in terms of their net biogenic CO_2 emissions, but small enough to be manageable and understandable for stationary sources. The accounting framework can also accommodate subcategories for a more refined assessment, including:

(1) Forest-Derived Woody Biomass:

- Forest residues.
- Mill residues.
- Non-merchantable forest biomass.
- Timber roundwood harvest in a commercial market area.
- Roundwood harvest from a dedicated source.

(2) Agricultural Biomass:

- Conventional crops.
- Energy crops, including switchgrass and short-rotation woody crops (e.g., poplar).
- Crop residues.
- Processing byproducts.

(3) Waste Materials:

- Municipal solid waste (MSW).
- Construction & Demolition (C&D) Waste.
- Industrial Waste.
- Manure Management.
- Tire-Derived Wastes (TDW).
- Wastewater solids.

The appendix contains case studies that demonstrate how these categories of feedstocks can be assessed within the accounting framework.

5 Accounting Framework: Technical Description

Section 5 provides technical detail describing the accounting framework for adjusting a stationary source's biogenic emissions estimate on the basis of information about the carbon cycle. Component equations are presented here, along with definitions and descriptions of each term. In a supporting appendix, the case study application of the framework is demonstrated by computing its terms specifically for selected hypothetical cases.

The framework converts **Potential Gross Emissions** (PGE) from use of a biogenic feedstock in a stationary source to an estimate of **Net Biogenic Emissions** (NBE). NBE represents the net CO_2 emissions associated with using a biogenic feedstock at a stationary source, calculated per ton of feedstock input on an annual time step. The NBE is then used to calculate a **Biogenic Accounting Factor** (BAF), which gives the proportion of emissions that are a contribution to the atmosphere [BAF equals NBE/PGE]. As explained in Section 4, the framework provides a means for considering CO_2 emissions, direct emissions from feedstock use, sequestration in feedstock growth, sequestration of unburned or captured fractions, leakage, hauling/storage losses, CO_2 in commercial and post-combustion products derived from the feedstock, and changes in carbon stock (including direct land-use change and soil carbon impacts) on the land supplying the feedstock. The framework does not include estimates of other lifecycle GHG emissions. This framework omits emissions such as those from fossil fuel use or fertilizer application during feedstock production, though the terms could be expanded to include other GHGs for specific policy applications. A term for leakage is also included here, though detailed methods for calculating leakage are not presented.

Emissions are calculated for a calendar year unless otherwise noted, as some of the numbers in the calculations may be averages of stock changes or fluctuating annual increments over a number of years, as explained in Section 4. To maintain uniform terms throughout, and to be consistent with convention, all calculations are conducted in terms of metric tons of carbon dioxide equivalent (tCO_2e). However, the general framework as presented here is applicable to estimation of the atmospheric impact of CO_2 emissions (though specific applications of the framework could include other GHGs).

In developing the equation to define the accounting framework, each accounting term is labeled with both long and short symbolic forms (see Table 5-1).

Table 5-1: List of Key Accounting Terms, Symbols and Definitions

Accounting Term	Symbol	Definitional Note
Potential Gross Emissions	PGE	Carbon content in the biogenic feedstock used for energy at a stationary source, in metric tons of CO_2e.
Net Biogenic Emissions	NBE	Amount of biogenic feedstock combusted at a stationary source after accounting for CO_2e in products, biogenic feedstock growth, supply chain losses, site emissions change, and leakage.
Biogenic Accounting Factor	BAF	The fraction of Potential Gross Emissions that becomes a net biogenic CO_2 emission to the atmosphere from using a biologically based feedstock, taking into consideration feedstock characteristics such as growth/emission avoidance, carbon stored in products, and site sequestration effects.
Feedstock Needed	FEEDN	Tons of dry feedstock used at the stationary source for bioenergy use, in dry English tons.

Accounting Term	Symbol	Definitional Note
Carbon content of feedstock	Carbon content of feedstock	Carbon content of the dry feedstock.
Carbon to CO_2e conversion	Carbon to CO_2e	Value of 3.6667, from the conversion of elemental carbon to CO_2e (44/12), based on molecular weight of CO_2 (44) compared to that of elemental carbon (12).
English to metric tons conversion	English to Metric tons	Value equal to 0.9072, resulting from conversion from English tons to metric tons (2,000 lbs to 2,204.6226 lbs).
Carbon in Products	PRODC	Proportion of feedstock CO_2e embodied as carbon in products leaving a stationary source, such as ethanol or paper.
Sequestered Fraction	SEQP	Proportion of the feedstock CO_2e embodied as carbon in post-combustion residuals (such as ash or biochar) or carbon captured and stored before leaving the stack at a stationary source.
Proportion of Feedstock Lost	L	Proportion of additional feedstock necessary to overcome feedstocks losses in conveyance, storage, and plant handling.
Level of Atmosphere Reduction	LAR	Proportion of Potential Gross Emissions that are offset by sequestration during feedstock growth.
Leakage	LEAK	Represents the emissions leakage caused by diversion of materials from prior uses to use as a bioenergy feedstock, and the resulting change in biogenic CO_2e emissions or sequestration elsewhere expressed as net biogenic emissions of tCO_2e.
Total Net Change in Site Emissions	SITE_TNC	Feedstock production site-level difference in the net CO_2e flux to the atmosphere when biogenic feedstocks are used for bioenergy versus a previous use/activity considering both emissions and sequestration changes (e.g., in the case of land-use change or residue removal).
Tons of Feedstock Produced	TFP	Total site production necessary to provide the feedstock used by the stationary source, after accounting for losses between the production site and the stationary source, in dry English tons.
Feedstock Losses in Storage	Storage Losses	Assumed loss in storing the feedstock from the feedstock production/recovery site to the stationary source.
Feedstock Losses in Transport	Transport Losses	Assumed loss in transporting the feedstock from the production/recovery site to the stationary source.
Feedstock Losses in Processing at Stationary Source	Processing Losses	Assumed loss that occurs when handling and preparing the feedstock at the stationary source before feedstock consumption.
Growth	GROW	Metric tons of CO_2e that are sequestered in feedstock growth in the same year as the feedstock is removed or carbon sequestered through growth on an annualized basis.
Avoided Emissions	AVOIDEMIT	Emissions that would occur anyway from removal or diversion of non-growing/no longer-growing feedstocks items like corn stover and logging residues, in terms of tCO_2e.
Acres Needed	ACRES	Acres of land required to source the feedstock.
Change in Net Site Emissions	SITEEMIT	Net addition of biogenic CO_2e emissions due to the biogenic feedstock production/removal when compared to biogenic CO_2e emissions from previous land use or management.

Accounting Term	Symbol	Definitional Note
Change in Net Site Sequestration	SITESEQ	Net addition of biogenic CO_2e sequestration due to the biogenic feedstock production/removal when compared to biogenic CO_2e emissions from previous land use or management.
Yield per Acre	YIELD_ACRE	Average yield per acre of feedstock produced.
Total Net Change in Site Emissions per Acre	SITE_TNCacre	Total Net Change in Site Emissions calculated on a per acre basis.

5.1 The Framework

The accounting framework takes a number of steps to compute a **Biogenic Accounting Factor** (BAF) that adjusts the total onsite biogenic CO_2 emissions at a stationary source on the basis of the carbon cycle by considering feedstock characteristics such as growth, decay, carbon stored in products, leakage, and site sequestration effects. The BAF is specific to an individual feedstock type, produced in a defined geographic area, with an identified production framework, going into a defined stationary source production system. The **Biogenic Accounting Factor** (BAF) represented as a proportion, is calculated by dividing **Net Biogenic Emissions** (NBE) by **Potential Gross Emissions** (PGE):

$$\mathbf{BAF = NBE / PGE} \qquad \textbf{(EQ. 1)}$$

This equation results in a value that can be positive or negative, with negative values meaning there is more sequestration than emissions, and positive ones meaning the converse. For example, a **Biogenic Accounting Factor** (BAF) of:

- 0 would mean that the biogenic CO_2 emissions have no net atmospheric impact; in other words, biogenic processes sequester CO_2e (or avoid biogenic CO_2e emissions) at the feedstock production site and through related processing in an amount equivalent to the direct biogenic CO_2e emissions from a stationary source.

- 1 would mean that 100 percent of the biogenic CO_2 emissions are contributions to the atmosphere; in other words, biogenic processes offset none of the direct biogenic CO_2e emissions.

- A value between 0 and 1, such as 0.2 or 0.5 would mean that a proportion of the biogenic CO_2 emissions have a net atmospheric impact; in this case, biogenic processes offset 80 percent or 50 percent of the biogenic CO_2e emissions.

- −0.2 would mean that biogenic processes would sequester 20 percent more than the total of biogenic CO_2e emissions; for example, if biogenic feedstock growth sequesters CO_2 at the feedstock production site with very little or no land-use change coupled with a substantial amount of CO_2e that remains, after use for bioenergy, sequestered in ash, biochar, or CCS processes. For most feedstocks in most regions, this will not occur, but this equation can capture the instances in which it does occur.

Potential Gross Emissions (PGE) is based on the CO_2e content of the biogenic feedstock required at the stationary source for energy.[38] Calculation of PGE involves multiplying the weight of the primary **Feedstock Needed** (FEEDN) at the point of combustion at the stationary source, (in English tons) by the carbon content of the feedstock (Carbon content of feedstock) times a carbon to CO_2e conversion factor (Carbon to CO_2e) times a conversion factor to metric tons (English to Metric tons). This is reflected in Equation 2:

$$\begin{aligned}\textbf{PGE} = \textbf{FEEDN}\\ &\times \textbf{Carbon content of feedstock}\\ &\times \textbf{Carbon to } \mathbf{CO_2e}^{39}\\ &\times \textbf{English to Metric tons}^{40} \qquad \textbf{(EQ. 2)}\end{aligned}$$

Net Biogenic Emissions (NBE) recognizes that the **Potential Gross Emissions** (PGE) may not reflect the net atmospheric CO_2 impact of using a biogenic feedstock at a stationary source, since emissions from biogenic feedstocks (as opposed to fossil fuel feedstocks) are affected by several factors, including:

- Growth or renewal of the biogenic feedstock.
- Changes in the amount of CO_2e stored on the landscape due to biogenic feedstock production either in the form of emissions or sequestration increases.
- Biogenic CO_2e that leaves the stationary source embodied in commercial products such as ethanol, paper, or distillers dried grains (DDGs).[41]
- Biogenic CO_2e residuals that remain after feedstock use for bioenergy (post-combustion residuals), and are placed into sequestration, leaving the stationary source as carbon in ash, biochar, or in CCS activities.[42]
- Biogenic emissions stimulated elsewhere when the feedstock production reduces the supply of products entering the market and other places increase production causing indirect land use (i.e., leakage).

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[38] There will likely be losses in storage, transport, or processing, so the volume of material harvested from the landscape will generally exceed that used in the stationary source but will still be part of the harvest; these losses are accounted for in calculation of the Net Biogenic Emissions.

[39] Static value equal to 44/12

[40] Static value equal to 0.9072

[41] Commercial or final products created by the stationary source also play a key role in accounting for biogenic emissions at stationary sources. For example, when 100 tons of CO_2e in the form of a feedstock are input at a stationary source process (after accounting for conveyance and other supply chain losses) and 30 tons leave the stationary source as carbon in commercial products, such as paper, tables, or ethanol, then the accounting framework assumes that since 30 percent of the CO_2e leaves in the form of carbon in products that only 70 percent of the associated biogenic emissions are allocated to this stationary source as emissions (assuming no carbon is left post-combustion in ash or another form).

[42] Similar to carbon stored in commercial products, sequestration embodied in post-combustion residuals or carbon captured and stored (e.g., carbon stored in ash, CCS activities) also play an important role when accounting for net biogenic emissions at stationary sources. In some cases, these post-combustion materials are sold, which can be reflected in the framework calculation as Carbon in Products (PRODC); if the stationary source is responsible for disposal, it will be counted in Sequestered Fraction (SEQP).

Taking these factors into account, **Net Biogenic Emissions** (NBE) may be calculated using Equation 3:

$$
\begin{aligned}
\mathbf{NBE} = \mathbf{PGE} \times (\mathbf{1} + \mathbf{L}) \\
\times (\mathbf{1} - \mathbf{LAR}) \times (\mathbf{1} - \mathbf{PRODC}) \\
- \mathbf{PGE} \times \mathbf{SEQP} \\
+ \mathbf{SITE\_TNC} \times (\mathbf{1} - \mathbf{PRODC}) \\
+ \mathbf{LEAK} \times (\mathbf{1} - \mathbf{PRODC}) \qquad \mathbf{(EQ.3)}
\end{aligned}
$$

Definitions for the lines in the above equation are:

- Multiplying **Potential Gross Emissions** (PGE) by (1 + L) gives the amount of potential emissions from the total feedstock that is produced in order to supply the feedstock needed at the source. The (1+L) terms adjusts PGE upward to account for feedstock losses in conveyance, storage, and plant handling prior to use by the stationary source. This is based on the amount of feedstock that must be collected at the feedstock production site (**Feedstock Needed**) in order to meet the demand required at a particular stationary source accounting for the proportion lost between the collection point and the stationary source.

- **Level of Atmosphere Reduction** (LAR) is the proportional atmospheric CO_2e reduction from either sequestration during feedstock growth. Thus multiplying PGE by (1 − LAR) gives the amount of CO_2e that is not offset by growth. When LAR equals one, all the biogenic CO_2 emissions are offset and when it equals zero none of the biogenic CO_2 emissions are offset. An LAR term between 0 and 1 means some proportion of biogenic CO_2e emissions from the stationary source is offset (if LAR goes above 1, this is reflected as 1).

- **Carbon in Products** (PRODC) is the proportion of CO_2e embodied as carbon in commercial products leaving the stationary source. For example, an ethanol plant will transform biological feedstock into a fuel that is sold to the market. While the carbon will almost entirely end up as CO_2 when eventually combusted, the CO_2 is not emitted by the plant. This framework does not include "downstream" lifecycle emissions. Thus, multiplying the previous term by (1 − PRODC) adjusts PGE to account for the biogenic carbon content of commercial products (such as paper, lumber or ethanol) leaving the stationary source, allocating a share of this change to the products leaving the stationary source.

- **Sequestered Fraction** (SEQP) is the proportion of the feedstock carbon content that is not released during combustion (e.g., through incomplete combustion or CCS) and remains sequestered in post-combustion byproducts (which is different than carbon stored in products represented by PRODC) at the stationary source. In some production technologies, for example, virtually all of the carbon in the biogenic feedstock combusted by the stationary source is emitted as CO_2. In that event, the **Sequestered Fraction** would be 0 or very close to 0. In other technologies, some carbon is left in ash or biochar post-feedstock combustion. If such post-combustion byproducts are sold (rather than disposed of), these will be included in the PRODC term. Alternatively, this term may be used when carbon is captured before it can go up the stack and then stored (e.g., through CCS). In Equation 3, subtracting

Potential Gross Emissions multiplied by **Sequestered Fraction** (− PGE × SEQP) adjusts PGE to account for the amount of potential CO_2e emissions that are sequestered in combustion residuals at the stationary source.

- **Total Net Change in Site Emissions** (SITE_TNC) is the annualized difference[43] in the stock of land-based carbon (above- and below-ground, including changes in standing biomass and soil carbon) in tCO_2e that results on the site where the feedstock is produced. This is accounted for in tCO_2e and accounts for effects from changing land use or management from a prior utilization/management pattern to biogenic feedstock production. In many cases, there may be no difference. If there is a difference, this change can be positive or negative and is likely to occur over a period of years. Estimation of SITE_TNC involves accounting for what happens on the site before making changes for feedstock removal versus what happens after. This term is multiplied by (1 − PRODC) to adjust for the share of emissions embodied as carbon in products leaving the stationary source, allocating a share of this change to the products leaving the stationary source.

- **Leakage** (LEAK) is the unanticipated decrease or increase in GHG emissions outside of the project's accounting boundary as a result of project activities (i.e., replacement of diverted crop, livestock or forest products due to a change in land use from conventional products to biomass feedstocks). The term is expressed as net emissions in tCO_2e that occur when producing the feedstock supply needed for the stationary source. This is multiplied by (1 − PRODC) to adjust for the share of emissions embodied as carbon in products leaving the stationary source, allocating a share of this change to the products leaving the stationary source.

Using this accounting method, it is possible that for certain feedstocks from certain places that go through certain production processes, the **Biogenic Accounting Factor** (BAF) will be at or near zero, and **Net Biogenic Emissions** (NBE) will equal or nearly equal zero. For other combinations of feedstock, location and production, the BAF will be at or near 1, and NBE will be at or near PGE. Many combinations, however, may fall somewhere in between. Large sequestration fractions coupled with feedstock growth of nearly 100 percent and/or the inclusion of CCS could result in a negative BAF value, indicating that more CO_2e is removed from the atmosphere than emitted. Similarly, under some conditions, for example where leakage is substantial and measurable, or where direct land-use change causes a substantial decline in soil carbon stocks, it may be possible for the BAF to be greater than 1.

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[43] "Annualized differences" can represent the shift of a system from one level of carbon stocks to some new level over time (presuming carbon stocks eventually reach a new steady state under the new management).

Figure 5-1 and Figure 5-2 represent the carbon flows associated with the general accounting framework for accounting for biogenic CO_2 emissions from stationary sources. In both Figures, the red portions of the arrows correspond to flows to and from the atmosphere (these are attributed to the stationary source), while the blue portions correspond to flows that are passed through the framework but are assigned to products or are sequestered. Figure 5-1 (top) uses text to describe the flows, while Figure 5-2 (bottom) uses the terms in the accounting framework equation. Note that the magnitudes of the flows and the corresponding arrows within the framework will vary depending on the application.

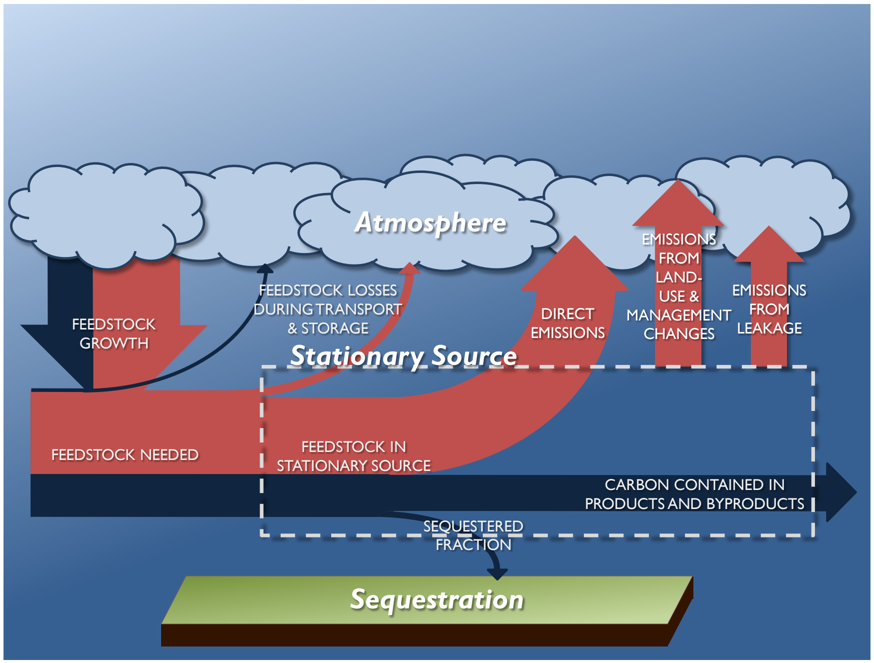

Figure 5-1: Overview of carbon flows within the Accounting Framework

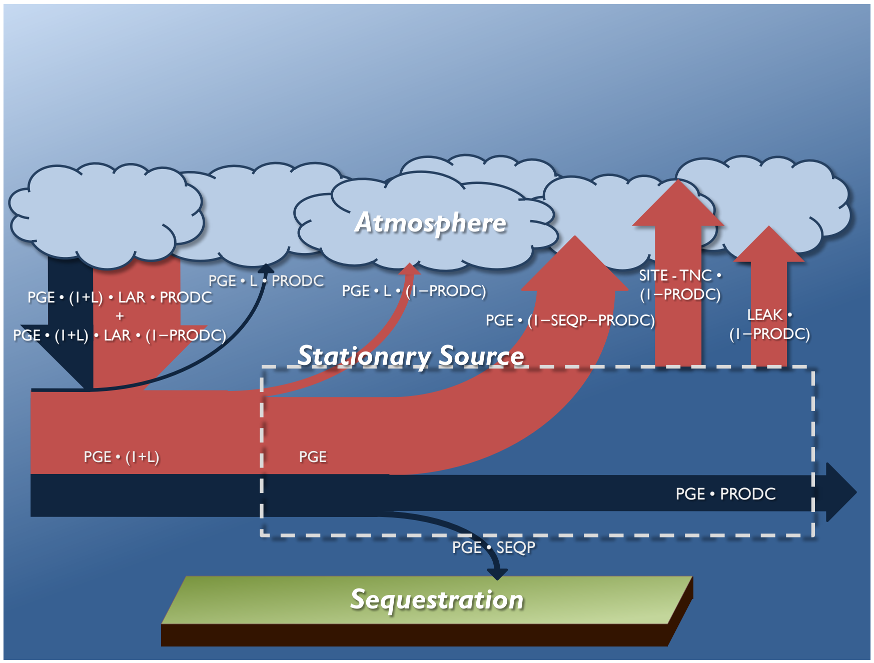

Figure 5-2: Equation terms associated with carbon flows in the Accounting Framework.

In Figure 5-2, note that only a portion—the terms with multiplier (1 − PRODC)—of the feedstock growth and hauling/storage loss flows are attributed to the stationary source, since the remaining portion—the terms with multiplier PRODC—of these flows is attributed to the carbon contained in products and byproducts.

5.2 Step-by-Step Calculations

Additional details on how to compute each of the terms in the accounting framework above are shown below. Generally, unless otherwise stated, the calculations of terms in the basic framework equation result in a measure of tCO_2e attributable to the production and use of the total tons of feedstock used in the stationary source, including biogenic emissions, losses along the supply chain, commercial products and post-combustion materials. This is required in order to keep the terms of the equation in consistent measures.

A. Computing Potential Gross Emissions (PGE)

As presented in Section 5.1, the equation for **Potential Gross Emissions** (PGE) is as follows:

$$\begin{aligned} \textbf{PGE} = \textbf{FEEDN} & \\ & \times \textbf{Carbon content of feedstock} \\ & \times \textbf{Carbon to CO}_2\textbf{e}^{44} \\ & \times \textbf{English to Metric tons}^{45} \qquad \textbf{(EQ. 2)} \end{aligned}$$

This calculation takes the feedstock needed (assumed to be in tons) times the proportional carbon content adjusted to CO_2 and then to metric tons.

As an example, here is the calculation for the **Potential Gross Emissions** (PGE) for a feedstock needed volume of 1,000 tons of dry roundwood, assuming that the carbon content of dry roundwood is 50 percent, and assuming that at this point no material is diverted for use in other products:[46]

$$\text{PGE} = 1{,}000 \times 0.5 \times 3.6667 \times 0.9072 \approx 1{,}660 \text{ tCO}_2\text{e}$$

Thus, the total potential biogenic CO_2e emissions using 1,000 tons of dry wood delivered to a stationary source would be approximately 1,660 metric tons.

B. Computing Proportion of Feedstock Lost

Proportion of Feedstock Lost (L) is the proportion of additional feedstock production needed to overcome losses in conveyance, storage, and plant handling.

To calculate this proportion, one must first calculate the **Tons of Feedstock Produced** (TFP), which is equal to the tons of dry **Feedstock Needed** (FEEDN) adjusted upward for losses in processing, storage, and hauling:

$$\begin{aligned} \textbf{TFP} = \textbf{FEEDN} & \\ & \times \textbf{(1 + Plant Losses)} \\ & \times \textbf{(1 + Storage Losses)} \end{aligned}$$

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[44] Static value equal to 44/12

[45] Static value equal to 0.9072

[46] Note that, in this example, it is assumed that the weight of the freshly harvested feedstock has been multiplied by its moisture content to arrive at a bone-dry weight equivalent.

$$\times (1 + \text{Transport Losses}) \qquad \textbf{(EQ. 4)}$$

TFP represents the tons of **Feedstock Needed** (FEEDN) to be procured from the feedstock production site to achieve the desired level of energy production after accounting for losses along the supply chain.

Proportion of Feedstock Lost (L) is the proportion of assumed losses per ton of feedstock inputs relative to the tons of **Feedstock Needed** (FEEDN) for combustion at the stationary source. This reflects the **Tons of Feedstock Produced** (TFP), which accounts for biogenic feedstock needed for combustion plus losses at the plant, in storage, and in hauling, divided by the tons of feedstock lost minus one. In equation form, this is:

$$L = (TFP / PGE) - 1 \qquad \textbf{(EQ. 5)}$$

Calculation of the loss term yields the proportion of usable tons of feedstock lost between the production site and processing within the stationary source. For example, for switchgrass, transport losses are estimated to be on the order of 5 percent, storage losses are 15 percent if the material is not covered in storage,[47] and yield lost in processing is around 1 percent. Taking the case of switchgrass that is uncovered during storage, 21 percent more feedstock would need to be grown and harvested than is used in the stationary source. Other feedstocks may need similar calculations with applicable loss numbers where available. Some feedstocks, like forest products, corn grain, or waste materials, for example, may experience little or none of these losses.

C. Computing Level of Atmosphere Reduction

Level of Atmosphere Reduction (LAR) is the proportion of **Potential Gross Emissions** (PGE) that are offset by either feedstock **Growth** (GROW), on a concurrent annualized basis. For example, if LAR equals one, this means that the level of atmospheric reductions (through feedstock growth) will be equal to or more than PGE (a similar outcome as categorical exclusion, as discussed in Section 2).

Level of Atmosphere Reduction (LAR) is calculated as follows:

$$LAR = (GROW + AVOIDEMIT)$$

$$/ (PGE \times (1 + L)) \qquad \textbf{(EQ. 6)}$$

Definitions for terms in this equation are as follows:

- **Growth** (GROW) represents the tons of CO_2 that are sequestered in feedstock growth in the same year as the feedstock is removed. For example, in the case of forests that are managed for wood production and other values on a long-term rotation, annualized growth is calculated on the basis of the annual change in above-ground live tree biomass as indicated by measured or modeled inventories across the spatial area of the accounting scope (this will be done using a 5-year moving average for forests and perennials). The size of the forest landscape chosen for the accounting scope is an important factor in the forestry and perennial case, and will be discussed below.

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[47] Storage losses are generally about 4 percent if the material is covered while in storage.

- **Avoided Emissions** (AVOIDEMIT) are the emissions that would have occurred anyway without the removal or diversion of non-growing items like animal manure, corn stover, and logging residues. This is the alternative profile of emissions of biogenic CO_2e in terms of CO_2e emissions that would have occurred without removal or diversion for bioenergy use ("anyway emissions").

Applications of the accounting framework to specific policies or programs may need to distinguish between two different sets of calculations or approaches to Equation 6 to include: (1) specific calculations of net emissions for existing facilities, in which the feedstock consumption has already been factored into estimates of net regional growth; and/or (2) specific calculations of net emissions for proposed new facilities, in which their estimated feedstock demand has not yet been factored into estimates of regional net growth and thus their anticipated emission values need to be added to the existing regional removals to get the total removals contemplated upon installation of the new stationary source. In the case of new stationary sources, the size of the new entity may be a significant determinant when considering the future net impacts of biogenic feedstock use on the regional carbon stocks. This would be especially important in regions that are on the threshold, meaning that they are stable or slightly increasing, but sizable increased demand for feedstocks in that region could cause carbon stocks to decline.

D. Computing Carbon in Products

The proportion of carbon contained in products made from use of biogenic feedstocks at a stationary source also plays a role when calculating the BAF. For example, when a stationary source produces products like lumber, ethanol, or DDGs, adjustments must be made to account for the CO_2e content of those products that will be used and possibly ultimately emitted outside the plant. This accounting framework recognizes the share of PGE that is contained as carbon in products leaving the stationary source. The **Carbon in Products** (PRODC) is the proportion of CO_2e content in all commercial products leaving the stationary source (excluding combustion residual and other disposed-of items like ash, as these are counted in the **Sequestration Fraction** term explained below). The PRODC formula here is:

$$\textbf{PRODC} = \textbf{Carbon content of Products} \,/\, \textbf{PGE} \qquad \textbf{(EQ.7)}$$

In turn, multiplying the other equation terms by (1 − PRODC) attributes a share of that term to the ultimate products, or conversely reduces the share attributable to the stationary source by the amount of carbon being passed on in products.

E. Computing Sequestered Fraction

Sequestered Fraction (SEQP) is the proportion of CO_2e that remains in the form of carbon in post-combustion residual products (e.g., from incomplete combustion) or biogenic CO_2 emissions that are captured and stored instead of being released into the atmosphere when the feedstock is combusted or processed (CCS). This term is distinguished from PRODC, as that term represented commercial products that are sold and leave the stationary source, such as paper, wooden tables, DDGs, or ethanol. Examples of SEQP include sequestration associated with incomplete combustion such as ash or biochar, or active sequestration activities, such as CCS. It is acknowledged that in some cases, post-combustion materials such as ash or biochar are sold (as opposed to materials whose disposal must be paid for by a stationary source). In such cases, these materials are counted in the PRODC term rather than in SEQP. SEQP is calculated by dividing the CO_2e that is sequestered by the **Potential Gross Emissions** of a stationary source:

$$\textbf{SEQP} = (\textbf{CO}_2\textbf{e in combustion residuals} + \textbf{CO}_2\textbf{e captured from the stack and stored}) / \textbf{PGE} \qquad \textbf{(EQ. 8)}$$

F. Computing Total Net Change in Site Emissions (SITE_TNC)

Total Net Change in Site Emissions (SITE_TNC) is the site-level difference in the net CO_2e flux to the atmosphere when biogenic feedstocks are used at a stationary source for bioenergy versus a previous use/activity. Specifically, this term accounts for the change in net biogenic CO_2 emissions and/or sequestration due to feedstock production/removal for bioenergy use on the feedstock production site, compared with emissions/sequestration that occur without production/removal of the feedstock for bioenergy. This computation considers the difference between two cases:

- Net biogenic CO_2 emissions amount (emissions minus sequestration) without production or removal of the feedstock for bioenergy use.
- Net biogenic CO_2 emission amount (emissions minus sequestration) that occurs with feedstock production/removal.

Total Net Change in Site Emissions (SITE_TNC) can be expressed in terms of **Change in Net Site Emissions** (SITEEMIT) and **Change in Net Site Sequestration** (SITESEQ), as reflected in Equation 9:

$$\textbf{SITE\_TNC} = (\textbf{SITEEMIT}) - (\textbf{SITESEQ}) \qquad \textbf{(EQ. 9)}$$

This framework focuses on differences in net biogenic emissions and sequestration at the site between uses. Definitions for terms in this equation are as follows:

- **Change in Net Site Emissions** (SITEEMIT) is the net addition to CO_2e emissions due to the feedstock production/removal (being negative if emissions are reduced). For example, when a forest is harvested, emissions may increase due to losses in soil carbon storage from harvesting disturbance plus emissions from any logging residues left to decompose. Note that these estimates were not included in the **Level of Atmosphere Reduction** term, which in managed forests was limited to the change in above-ground live tree biomass. This term may frequently be zero, particularly where regional estimates are the basis for the analysis.
- **Change in Net Site Sequestration** (SITESEQ) is the net addition to sequestration due to the feedstock production/removal. An example would be the added sequestration when land used to grow corn is converted to growing energy crops like poplar, whereas the increased sequestration comes from soil sequestration gains plus that in standing poplar. Average standing vegetation estimates can be counted as added sequestration for vegetation that stands for more than one year.

To calculate these items, we need to first calculate the land involved then the per-acre counterparts of SITEEMIT and SITESEQ.

1. How Much Land is Involved

An important component of implementing the **Total Net Change in Site Emissions** (SITE_TNC) calculation involves the land needed to produce agricultural and forestry feedstocks. This calculation is not as simple as computing the tonnage of feedstocks divided by feedstock yield per acre, due to the need to account for losses in transport, storage, and preprocessing.

To calculate **Acres Needed** (ACRES) (i.e., the acres of land required to produce the feedstock), one must take into account the total feedstock needed at the stationary source adjusted to account for losses along the feedstock supply chain (i.e., **Tons of Feedstock Produced**, TFP) then divide that by the average **Yield per Acre** (YIELD_ACRE) of the biogenic feedstock.

$$\mathbf{ACRES = TFP\ /\ YIELD\_ACRE} \qquad \mathbf{(EQ.\ 10)}$$

2. Calculating Sequestration and Emission Terms

When **Acres Needed** (ACRES) has been computed, then **Total Net Change in Site Emissions** (SITE_TNC) can be calculated on a per-acre basis (SITE_TNCacre) scaled up to all acres. In forests, where exact acres may not be known, the calculations can either be made on a per-acre basis (based on average regional yields), or they can be related directly to the tons of feedstock consumed (tCO_2e of sequestration or emission change per tCO_2e of feedstock consumed). Suppose the per-acre counterparts to the above terms are the terms computed. Equation 11 shows this formula:

$$\begin{aligned}\mathbf{SITE\_TNCacre} &= \mathbf{(SITEEMIT\ per\ acre - SITESEQ\ per\ acre)}\\ &\quad \times \mathbf{ACRES} \qquad \mathbf{(EQ.\ 11)}\end{aligned}$$

The **Total Change in Net Site Sequestration per Acre** (SITE_TNCacre) equals sequestration with biogenic feedstock removal per acre minus sequestration in the previous use case per acre adjusted to a per year basis. The fundamental point of departure for this term involves whether or not land-use changes.

5.3 Calculation of BAF

Ultimately the multiple steps laid out in this accounting framework equation compute a **Biogenic Accounting Factor** (BAF), represented as a proportion, that adjusts the total onsite biogenic CO_2 emissions at a stationary source on the basis of the carbon cycle. It does so by considering first **Potential Gross Emissions** (PGE) from the stationary source along with feedstock characteristics such as growth, decay, carbon stored in products, leakage, and site sequestration effects. These components are reflected in the calculation of **Net Biogenic Emissions** (NBE):

$$\begin{aligned}\mathbf{NBE} &= \mathbf{PGE \times (1 + L)}\\ &\quad \mathbf{\times (1 - FR) \times (1 - PRODC)}\\ &\quad \mathbf{- PGE \times SEQP}\\ &\quad \mathbf{+ SITE\_TNC \times (1 - PRODC)}\\ &\quad \mathbf{+ LEAK \times (1 - PRODC)}\end{aligned}$$

With PGE and NBE calculated, the proportion of net biogenic CO_2 emissions at the stationary source can be calculate as the **Biogenic Accounting Factor** (BAF):

BAF = NBE / PGE

6 Conclusion

This report details the scientific and technical issues associated with accounting for biogenic CO_2 emissions at stationary sources. It includes an overview of the related components of the carbon cycle, and then provides a discussion of the factors that can influence the development of an accounting framework for biogenic CO_2 emissions, such as sequestration, spatial and temporal scale, GHGs included, and other considerations. Based on that description, for a specific policy context in which a stationary source emitting biogenic CO_2 requires a means to adjust its total onsite biogenic emissions on the basis of the carbon cycle, the report presents a general accounting framework.

The framework provides the critical link from the direct emissions at the stationary source to the offsite factors related to the carbon cycle in a scientifically and technically rigorous manner, through the development of a BAF. The use of the BAF to adjust the total onsite biogenic emissions at a stationary source may allow for a more accurate assessment than "gross emissions" or default "carbon neutrality," because it acknowledges the role of the carbon cycle.

While the accounting framework is generally applicable to biogenic CO_2 emissions at stationary sources, to ensure it can be adapted to specific program and policy needs it was developed based on the following criteria:

- Accurately reflects the carbon outcome.
- Is scientifically rigorous/defensible.
- Is simple and easy to understand.
- Is simple and easy to implement.
- Is easily updated with new data.
- Uses existing data sources.

These criteria are important because both the development of the framework itself and any adaptation to a particular program involve specific policy decisions depending on the requirements and objectives. The dissection of the technical issues and factors in Section 3, the presentation of the framework in Sections 4 and 5, and the case studies in the appendix highlight the implications of the different decisions and explain the rationale for any decisions EPA did make in developing the framework.

For example, this framework suggests that biologically based feedstocks fall into three major categories that are functionally similar: (1) forest-derived woody biomass, (2) agricultural biomass, and (3) waste materials. As demonstrated by the characteristics of these feedstocks and the case studies in the appendix, the agricultural feedstocks may have a BAF of 0 due to the annual growth/harvest cycle. Therefore, depending on the program, it may be appropriate to treat those feedstocks differently from other types of feedstocks used at stationary sources.

Furthermore, when adapting this framework, it will be important to consider other complementary policies related to biogenic CO_2 emissions. For example, there might be policies affecting land owners that influence the way land and feedstocks are managed, such as forest conservation, zoning, and biomass certification programs (e.g., owners of stationary sources may also be landowners and may be able to demonstrate that their feedstocks all come from lands that are managed in ways that maintain or increase carbon stocks). In addition, different types of stationary sources (e.g., Combined Heat and Power) use biomass with varying degrees of efficiency (e.g., tons feedstock required per MW or British thermal unit (BTU)), and efficiency may be an important consideration under certain policies and programs.

These and other issues will be critical in implementing this or similar accounting frameworks for stationary sources that use biologically based feedstocks. This report highlights the fact that accounting for biogenic CO_2 emissions at stationary sources can be complex and there are many factors influencing the carbon cycle, so that no one approach will likely be sufficient in all cases. At the same time, this report demonstrates that it is possible to adjust the total onsite biogenic emissions at the stationary source on the basis of the carbon cycle in a technically and scientifically rigorous manner.

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Glossary of Terms

Accounting Framework: General method for adjusting estimates of onsite *biogenic CO_2 emissions* on the basis of information about growth and avoided *emissions*, and more generally the *carbon cycle*, with the end goal of providing a more meaningful characterization of the impact of these *emissions*.

Anthropogenic: Resulting from or produced by human beings.

Baseline: The baseline (or reference) is any datum against which change is measured. Such a datum serves as the "reference" against which other conditions or changes can be compared. 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.

Biochar: Charcoal created by pyrolysis of *biogenic feedstock*.

Bioenergy: Energy derived from *biomass*.

Biogenic Accounting Factor (BAF): The fraction of Potential Gross Emissions that becomes a net *biogenic CO_2 emission* to the atmosphere from using a *biologically based* feedstock, taking into consideration feedstock characteristics such as growth and emission avoidance, *carbon* stored in products, and site *sequestration* effects.

Biogenic CO_2 Emissions: *Carbon dioxide emissions* directly resulting from the combustion, decomposition, or processing of *biologically based* materials other than *fossil fuels*, peat, and mineral sources of *carbon* through combustion, digestion, fermentation, or decomposition processes.

Biogenic Feedstock: *Biologically based* materials that are used for combustion, product processes, or otherwise decompose at a *stationary source*.

Biologically based: Non-fossilized and biodegradable organic material originating from modern or contemporarily grown plants, animals, or microorganisms (including products, *byproducts*, residues and wastes from agriculture, forestry, and related industries as well as the non-fossilized and biodegradable organic fractions of industrial and municipal wastes, including gases and liquids recovered from the decomposition of non-fossilized and biodegradable organic material).

Biomass: Organic material both above-ground and below-ground, and both living and dead, e.g., trees, crops, grasses, tree litter, roots etc. Biomass literally means living matter, but the term is also used for any organic material derived from plant and animal tissue. In the context of *bioenergy*, biomass is any material of biological origin, excluding material embedded in geological formations and transformed to fossil.

Byproduct: A material of value produced as a residual of, or incidental to, the combustion process.

Carbon: Chemical element with symbol C and atomic number 6. The abundance and unique diversity of organic compounds that it forms make this element the chemical basis for all known life.

Carbon Capture and Storage (CCS): CCS refers to a set of technologies that can reduce *carbon dioxide* (CO_2) *emissions* from *stationary sources* of CO_2 through a three-step process that includes capture and compression of CO_2 from stationary sources; transport of the captured CO_2 (usually in pipelines); and storage of that CO_2 in geologic formations, such as deep saline formations, oil and gas reservoirs, and unmineable coal seams.

Carbon Cycle: The term used to describe the flow of carbon (in various forms, e.g., as *carbon dioxide*) through the atmosphere, ocean, terrestrial biosphere, and lithosphere.

Carbon Debt: The net *greenhouse gas* implications of conversion of lands with substantial carbon stocks to intensive production of an annual feedstock.

Carbon Dioxide (CO_2): A naturally occurring gas, also a *byproduct* of burning *fossil fuels* from fossil carbon deposits, such as oil, gas and coal; of burning *biomass*; and of *land-use changes* and other industrial processes. It is the principal *anthropogenic greenhouse gas* that affects the Earth's radiative balance. It is the reference gas against which other greenhouse gases are measured and therefore has a *Global Warming Potential* of 1.

Carbon Dioxide Equivalent (CO_2e): Number of metric tons of CO_2 *emissions* with the same *Global Warming Potential (GWP)* as one metric ton of another primary *greenhouse gas*.

Carbon Flux: Transfer of *carbon* from one *carbon pool* to another in units of measurement of mass per unit of area and time.

Carbon Pool: A system with the capacity to accumulate or release *carbon*. Examples of *carbon pools* are forest biomass, wood products, soils, and the atmosphere.

Carbon Stocks: See *reservoir*.

Direct Land-Use Change: *Land-use change* that occurs when land within the system boundaries of an *accounting framework* is brought into production for a *biogenic feedstock* that was previously in another land use.

Distiller Dried Grains (DDG): Dried residue remaining after the starch fraction of corn is fermented with selected yeasts and enzymes to produce ethanol and *carbon dioxide*. After complete fermentation, the alcohol is removed by distillation and the remaining fermentation residues are dried.

Emissions: Release of *greenhouse gases* and/or their precursors into the atmosphere over a specified area and period of time. Direct emissions are defined at the point in the energy chain where they are released and are attributed to that point in the energy chain (the "point of emission"), whether it is a sector, a technology, or an activity. For example, emissions from coal-fired power plants are considered direct emissions from the energy supply sector. Indirect emissions, or emissions "allocated to the end-use sector," refer to the energy use in end-use sectors and account for the emissions associated with the upstream production of the end-use energy. For example, some emissions associated with electricity generation can be attributed to the buildings sector, corresponding to the building sector's use of electricity.

Fossil Fuel: Natural gas, petroleum, coal, or any form of carbon-based solid, liquid, or gaseous fuel derived from fossil hydrocarbon deposits.

Fossil Fuel Emissions: *Emissions* of *greenhouse gases* (in particular CO_2) resulting from the combustion of carbon-based fuels from fossil hydrocarbon deposits such as oil, gas, and coal.

Greenhouse Gases (GHGs): Gaseous constituents of the atmosphere, both *natural* and *anthropogenic*, that absorb and emit radiation at specific wavelengths within the spectrum of thermal infrared radiation emitted by the Earth's surface, the atmosphere itself, and by clouds. This property causes the greenhouse effect. Water vapor (H_2O), *carbon dioxide* (CO_2), nitrous oxide (N_2O), methane (CH_4), and ozone (O_3) are the primary greenhouse gases in the Earth's atmosphere. Moreover, there are a number of entirely human-made greenhouse gases in the atmosphere, such as the halocarbons and other chlorine- and bromine-containing substances, addressed under the Montreal Protocol. Beside *CO_2*, N_2O and CH_4, the Kyoto Protocol deals with the greenhouse gases sulfur hexafluoride (SF_6), hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs).

Gross Primary Production (GPP): The rate at which *photosynthetic* organisms capture chemical energy in their *biomass*.

Global Warming Potential (GWP): An index, based upon radiative properties of well-mixed *greenhouse gases*, measuring the *radiative forcing* of a unit mass of a given well-mixed greenhouse gas in the present-day atmosphere integrated over a chosen time horizon, relative to that of *carbon dioxide*. The GWP represents the combined effect of the differing times these gases remain in the atmosphere and their relative effectiveness in absorbing outgoing thermal infrared radiation.

Indirect Land-Use Change: Changes in production of a *biologically based* feedstock to meet demand created by a *stationary source* could stimulate *land-use change* and resulting *GHG* emissions outside the accounting boundary, if that feedstock demand reduces the market supply of feedstock-related commodities for other uses.

Land Use: Land use refers to the total of arrangements, activities and inputs undertaken in a certain land cover type (a set of human actions). The term land use is also used in the sense of the social and economic purposes for which land is managed (e.g., grazing, timber extraction, and conservation).

Land-Use Change: A change in the use or management of land by humans, which may lead to a change in land cover.

Leakage: Leakage refers to the indirect impact that a targeted activity in a certain place at a certain time has on carbon storage at another place or time. Leakage may include carbon flows that are large and predictable.

Lifecycle Analysis: Compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle. In the context of *greenhouse gas* assessments, lifecycle greenhouse gas *emissions* are the aggregate quantity of greenhouse gases related to the full fuel cycle, including all stages of fuel and feedstock production and distribution, from feedstock generation and extraction through distribution and delivery and use of the finished fuel.

Managed Forest: All forests subject to some kind of human interactions (notably commercial management, harvest of industrial roundwood (logs) and fuelwood, production and use of wood commodities, and forest managed for amenity value or environmental protection if specified by the country), with defined geographical boundaries.

Natural: Having or constituting a classification based on features existing in nature. *Carbon fluxes* are categorized as natural if the flux is caused by something beyond human control.

Policy-Relevant Timescale: The timeframe of concern required for stabilization of atmospheric *greenhouse gas* concentrations to avoid dangerous *anthropogenic* interference with the climate system.

Photosynthesis: The process by which plants take *carbon dioxide* from the air (or bicarbonate in water) to build carbohydrates, releasing oxygen in the process. There are several pathways of photosynthesis with different responses to atmospheric carbon dioxide concentrations.

Radiative Forcing: Radiative forcing is the change in the net, downward minus upward, irradiance (expressed in W/m^2) at the tropopause due to a change in an external driver of climate change, such as, for example, a change in the concentration of *carbon dioxide* or the output of the Sun. Radiative forcing is computed with all tropospheric properties held fixed at their unperturbed values, and after allowing for stratospheric temperatures, if perturbed, to readjust to radiative-dynamical equilibrium. Radiative forcing is called instantaneous if no change in stratospheric temperature is accounted for. For the purposes of this report, radiative forcing is further defined as the change relative to the year 1750 and, unless otherwise noted, refers to a global and annual average value. Radiative forcing is not to be confused with cloud radiative forcing, a similar terminology for describing an unrelated measure of the impact of clouds on the irradiance at the top of the atmosphere.

Reservoirs: A component of the climate system, other than the atmosphere, which has the capacity to store, accumulate, or release a substance of concern; for example, *carbon*, a *greenhouse gas*, or a greenhouse gas precursor. Oceans, soils, and forests are examples of reservoirs of carbon. “Pool” is an equivalent term (note that the definition of pool often includes the atmosphere). The absolute quantity of the substance of concern held within a reservoir at a specified time is called the *carbon stock*.

Scope: Components included as part of the system boundary for an *accounting framework*.

Sequestration: The addition of a substance of concern to a *reservoir*. The uptake of carbon-containing substances, in particular *carbon dioxide*, is often called (carbon) sequestration.

Sink: Any process, activity, or mechanism that removes a *greenhouse gas*, an aerosol, or a precursor of a greenhouse gas from the atmosphere.

Source: Any process or activity that releases a *greenhouse gas*, an aerosol, or a precursor of a greenhouse gas into the atmosphere.

Stationary Source: For the purpose of this study, a stationary source is any physical property, plant, building, facility, structure, or installation that emits or may emit *greenhouse gases*.

Tillage: Agricultural preparation of the soil by mechanical agitation.

Appendix: Case Studies

This appendix presents case studies to further illustrate the accounting methodology detailed in Sections 4 and 5. These case studies are organized as follows:

- Forest-Derived Woody Biomass:
    - Case Study 1: Calculating State versus Regional Net Biogenic Emissions from Electricity Generation using Harvested Roundwood in the Northeast United States.
    - Case Study 2: Calculating Net Biogenic Emissions from Electricity Generation Using Roundwood Harvested in the Northeast United States, Comparing the Average versus Marginal Method for Level of Atmospheric Reduction.
    - Case Study 3: Calculating Net Biogenic Emissions for a Pulp and Paper Mill Harvesting Roundwood in the Pacific Northwest.
- Agricultural Biomass:
    - Case Study 4: Calculating Net Biogenic Emissions from Converting Corn Stover to Electricity.
    - Case Study 5: Calculating Net Biogenic Emissions from Converting Short-Rotation Woody Energy Crop (Poplar) to Electricity.

Approach to Case Studies

The case studies presented in this Appendix are not an exhaustive list of all cases, nor are they definitive in terms of how this framework might be applied to specific stationary sources or source categories. They are for illustrative purposes only, and are presented here to accomplish two objectives: first, to demonstrate how the framework could be applied to stationary sources that typically emit biogenic CO_2, and second, to illustrate the implications of different policy choices on components of the framework.

For example, in the case of forest-derived biomass, the impacts of different spatial scales and feedstock types (e.g., mill residue versus roundwood) are presented. For agricultural biomass, the case studies presented cover corn stover and short rotation woody biomass. Though not included here as a case study, another example involving an annual crop is ethanol production facilities. We note that this framework would apply to the biogenic CO_2 emissions from ethanol production created from fermentation processes. The carbon that is embodied in the ethanol at the stationary source and used offsite would not be "counted" in this framework at the ethanol facility. Instead, that carbon would be "passed through" the framework.

As stated above, the case studies provide examples of how this framework could be applied in select cases, and reflect situations in which all data inputs required are readily available to individual stationary sources. If and/or when EPA chooses to adapt this framework to a specific program or policy, opportunities may exist to simplify the data inputs and required calculations without compromising scientific rigor. Those enhancements would be made in light of specific policy and program decisions regarding the use of the accounting framework, and may include such tools as regional look-up tables, spreadsheets with embedded calculations, and/or web-based data sources.

Depending on the program, a stationary source might be able to enter an online program, enter the relevant data about a particular situation, and receive the calculations needed to fulfill program requirements. Of course any tools, while suggested on a very general basis here, will require substantial refinement and development as policies and programs are designed, and as decisions regarding the applicability and use of the accounting framework are finalized. However, this framework is not designed to be a facility specific framework.

Approach to Biogenic CO_2 Emissions from Waste Materials

As discussed in Section 3 of the study, a critical difference between waste and other biologically based material is related to the connection to the land providing the material. The biologically based material in waste is initially removed from land for other economic purposes (e.g., for manufacture of consumer and industrial products such as newspaper, food, and construction). Given that the treatment of waste itself does not drive the management of the growth and harvesting of biomass, it is more difficult to quantify a connection between the consumption of waste at stationary sources and the positive or negative CO_2 impact on the atmosphere.

Therefore, for this accounting framework, BAF is considered to equal 0 for biogenic CO_2 released from waste decay at waste management systems, waste combustion at waste incinerators, or combustion of captured waste-derived CH_4.

If any portion of the material entering a waste incinerator is harvested specifically to be used at that incinerator, then it would need to be treated according to the methodologies provided in Sections 4 and 5 of this accounting framework.

Case Study 1: Calculating State versus Regional Net Biogenic Emissions from Electricity Generation using Harvested Roundwood in the Northeast United States

Description

This case study calculates the net biogenic CO_2 emissions from hypothetical existing and proposed electricity generating plants in the Northeast that use wood from surrounding forests as a feedstock. This case study illustrates the importance of defining the geographic extent of the feedstock source location for Net Biogenic Emissions (NBE) accounting. It also illustrates the difference in methods of calculating net emissions from an existing facility versus a proposed new facility. In particular, where a feedstock is sourced from a small landscape that currently has an increasing stock of carbon, but the proposed new facility demand would create declining carbon stocks (e.g., New Hampshire in the case study presented here), the proposed plant will have greater than zero NBE. For an existing plant, however, its feedstock use will have already been factored into the assessment of trends in regional carbon stocks, and if those stocks are increasing, then that plant will have had zero net emissions (assuming no effects of land-use or land management changes, and no leakage). However, in this same case, if accounting is done at the larger regional landscape level, the Northeast region has growing stocks of carbon that are much greater than the proposed removals from the new facility, and therefore the feedstock-derived emissions are assumed to be fully removed from the atmosphere via forest growth (i.e., will not contribute to an increase in atmospheric CO_2 levels).

Essential Features

This hypothetical case study assumes that:

- the existing or proposed plant has an output of 30 megawatts (MW) per year, is designed to run at 95 percent efficiency, converts 1 bone dry ton (BDT) of wood per megawatt-hour (MWh) of electricity produced, and would consume an input of 250,000 BDT of wood per year,
- the feedstock is sourced from harvest of low-grade roundwood, and does not compete with traditional timber and pulp markets, and
- there are no other forest-derived woody sources (e.g., mill byproducts, urban tree removals, logging residues) used as feedstocks for the hypothetical plant.

Overview

The accounting framework formula for Net Biogenic Emissions (NBE) is (Eqn. 3, Section 5.1 of the accounting framework):

$$
\begin{aligned}
\mathrm{NBE} = {} & [\mathrm{PGE} \times (1 + \mathrm{L}) \times (1 - \mathrm{LAR}) \times (1 - \mathrm{PRODC})] \\
& - [\mathrm{PGE} \times \mathrm{SEQP}] \\
& + [\mathrm{SITE\_TNC} \times (1 - \mathrm{PRODC})] \\
& + [\mathrm{LEAK} \times (1 - \mathrm{PRODC})]
\end{aligned}
$$

The following sections describe calculation of Net Biogenic Emissions (NBE) and the Biogenic Accounting Factor (BAF) in six steps:

Step 1: Potential Gross Emissions (PGE), Proportion of Feedstock Lost (L), Level of Atmospheric Reduction (LAR), and carbon leaving the accounting framework as products (PRODC)
Step 2: Carbon storage resulting from incomplete utilization (SEQP)
Step 3: Carbon Emissions/Sequestration at the Feedstock Production Site (SITE_TNC)
Step 4: Leakage (LEAK)
Step 5: Net Biogenic Emissions (NBE)
Step 6: Biogenic Accounting Factor (BAF)

Step 1: Potential Gross Emissions (PGE), feedstock carbon lost along supply chain (L), Level of Atmospheric Reduction (LAR), and carbon leaving the accounting framework as products (PRODC)

Step 1 begins with a calculation of the carbon that is contained in the feedstock as it leaves the farm gate or forest (Potential Gross Emissions, or PGE). Note that in this case, PGE is calculated with reference to the feedstock that is used by the facility, and then the proportion that is lost in transport, storage and handling (L) is added, in order to find the actual quantity of feedstock that must be produced on the land to support a particular facility's feedstock utilization.

- ***Calculating Potential Gross Emissions (PGE)***

Potential Gross Emissions (PGE) are the metric tons of biogenic CO_2e that could potentially be released from the stationary source stack. PGE is the product of the mass of feedstock used by the facility and its carbon content. Conversion factors are used to express PGE as metric tons CO_2e. See Table 3 for the values for each of the coefficients in this case study.

$$\text{PGE} = (\text{Feedstock needed})^{48} \times (\text{Carbon content of feedstock}) \times \text{English to Metric tons} \times \text{Carbon to } CO_2e$$

$$\text{PGE} = (250{,}000) \times 0.5 \times 0.9072 \times (44 / 12)$$

$$\text{PGE} = 415{,}800 \ tCO_2e$$

- ***Calculating Proportion of Feedstock Lost (L)***

In this case study, feedstock losses between forest and facility are assumed to be negligible, and thus L=0.

- ***Calculating Level of Atmospheric Reduction (LAR)***

Level of Atmospheric Reduction (LAR) is the proportional atmospheric CO_2e reduction that results from either (a) feedstock growth and sequestration of atmospheric CO_2, (GROW) or (b) avoided emissions that would have contributed to atmospheric CO_2e when the material decomposed (AVOIDEMIT) (for details, see Eqn. 6, Section 5.2.C of the accounting framework). Thus:

$$\text{LAR} = (\text{GROW} + \text{AVOIDEMIT}) / \text{PGE}$$

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[48] "Feedstock needed" refers to the amount of feedstock consumed by the facility, and could be quantified as actual (in the case of an existing facility) or projected (in the case of a new facility) consumption.

Note that avoided emissions are not relevant for this case study as there are no residue-based feedstocks, and we use PGE to indicate total emissions because there were no feedstock losses (L) between the production site and the facility.

For wood from forests:

LAR = 1 if feedstock removed is replaced by net growth of forest carbon within the source region, 0 if none of it is replaced, and a number between 0 and 1 if feedstock removed is only partially replaced.

Case 1: Existing Facility with a feedstock region defined as either an individual state (New Hampshire) or the entire Northeast region:

LAR = 1, because both the individual state and the entire region had a net increase in tree biomass on timberland during the reporting period, and—as this is an existing facility—feedstock consumption by the facility has been already factored into that determination of increasing carbon stocks.

Case 2: Emissions from a proposed new facility, using the entire Northeast as the source region defined for accounting purposes:

Annual Sequestration in the Source Region (i.e., net annual change in tree biomass on timberland) = 60,484,044 tCO_2e

LAR = 1 (or 100% of PGE) because the proposed annual feedstock consumption by the new facility is more than replaced by the current rate of annual sequestration, (i.e., $415{,}800\ tCO_2e \leq 60{,}484{,}044\ tCO_2e$.)

Case 3: Emissions from a proposed new facility, using the state of New Hampshire as the source region defined for accounting purposes:

GROW = Annual Sequestration (Net annual change in tree biomass on timberland)

LAR = 0.2507 (or 25.07% of PGE) because $104{,}252\ tCO_2e / 415{,}800\ tCO_2e = 0.2507$

- ***Calculating Carbon in Products (PRODC)***

Carbon in Products (PRODC) is the carbon content in commercial products, expressed in CO_2e, made from processing of the biogenic feedstocks, including energy products like ethanol and lignin that are combusted (or used) elsewhere (outside the stationary source), and non-energy products like paper or DDGS (Distiller's Dried Grains with Solubles) that are used elsewhere. In this case study, there is no Carbon in Products as the hypothetical electric generating facility does not produce co-products. Thus, PRODC = 0.

- ***Step 1: Conclusion***

Since L and PRODC are zero in this case study, the first term in the accounting formula simplifies to:

$[PGE \times (1 - LAR)]$

Case 1: Existing facility with either New Hampshire or the Northeast Region defined as the feedstock source region:

$= 415{,}800\ tCO_2e \times (1 - 1) = 0$

Case 2: Proposed new facility, with the Northeast Region defined as the feedstock source region:

$= 415{,}800\ tCO_2e \times (1 - 1) = 0$

Case 3: Proposed new facility, with New Hampshire defined as the feedstock source region:

$= 415{,}800\ tCO_2e \times (1 - 0.2507) = 311{,}559\ tCO_2$

Step 2: Carbon storage resulting from incomplete utilization

Step 2 calculates the difference between what could be emitted by utilization of the feedstock (PGE) when combusted fully and what is actually emitted as a result of the production of a Sequestered Fraction in the form of post-combustion material. This term can include carbon sequestered in residuals like ash or carbon sequestered through carbon capture technology. Note that if these materials are sold for use outside the stationary source rather than disposed of, they should be counted in PRODC.

The Sequestered Fraction (SEQP) is the proportion of the feedstock carbon content that is contained in the derivative materials that remain after biogenic feedstock combustion at the stationary source. In some production technologies, virtually all of the carbon in the feedstock is emitted as CO_2. In that event, Sequestered Fraction would be 0 or very close to 0. In other technologies, unburned carbon is left in the ash.

SEQP = CO_2e sequestered from stationary source / PGE

This case study assumes full combustion and consequently no Sequestered Fraction.

$SEQP = 0\ tCO_2e / 415{,}800\ tCO_2e = 0$

And thus,

$[PGE \times SEQP] = 415{,}800\ tCO_2e \times 0 = 0\ tCO_2e$

Step 3: Carbon emitted from the site where the feedstock was grown/collected (SITE_TNC)

The SITE_TNC term accounts for changes in the stock of land-based carbon (above and below ground) that may result from changes in land-use and land management associated with feedstock production. In the case of forest-derived feedstocks, the SITE_TNC term would be used to account for any net change in forest carbon stocks that might occur as a result of, for example, intensification of harvest practices (e.g., due to use of harvest residues). See Section 5.2.F of the accounting framework for details.

The SITE_TNC term has two components: Change in Net Site Emissions (SITEEMIT), (positive when harvest practices or land-use change result in a long-term net increase in CO_2 emissions from the land relative to what would happen in the absence of harvest), and Change in Net Site Sequestration (SITESEQ) (positive when harvest practices or land-use change result in a long-term net increase in CO_2 sequestration on the land relative to what would happen in the absence of harvest):

$$\text{SITE\_TNC} = \text{SITEEMIT} - \text{SITESEQ}$$

This case study assumes that feedstock was sourced from managed timberland, using established harvesting methods, and thus assumes that there are no changes in site CO_2 emissions or sequestration as a result of the feedstock production.

Thus SITEEMIT, SITESEQ and SITE_TNC are 0.

Step 4: Leakage (LEAK)[49]

Step 4 of the NBE formula accounts for effects of leakage or indirect land-use change. Specifically, LEAK is the leakage of biogenic carbon emissions generated outside the supply chain induced by market reactions to biogenic feedstock use for bioenergy (i.e., replacement of diverted crop, livestock or forest products due to a change in land use from conventional products to biomass feedstocks). The term is expressed as net emissions of metric tons CO_2e that occur when producing the feedstock volume needed for stationary combustion.

This case study assumes that no marketable wood was diverted from the market for traditional forest products into bioenergy, and LEAK is set to 0.

Step 5: Net Biogenic Emissions (NBE)

The calculation of Net Biogenic Emissions (NBE) combines the terms calculated in Steps 1–4:

$$\begin{aligned} \text{NBE} = {} & [\text{PGE} \times (1 + \text{L}) \times (1 - \text{LAR}) \times (1 - \text{PRODC})] \\ & - [\text{PGE} \times \text{SEQP}] \\ & + [\text{SITE\_TNC} \times (1 - \text{PRODC})] \\ & + [\text{LEAK} \times (1 - \text{PRODC})] \end{aligned}$$

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[49] As explained in Section 3 of the report, leakage is the unanticipated decrease or increase in GHG benefits (i.e., emissions) outside of a project's accounting boundary as a result of project activities. In these case studies, leakage refers to the biogenic CO_2 emissions generated outside the supply chain induced by market reactions to biogenic feedstock use for bioenergy (e.g., emissions caused by land use changes that result from replacement of the diverted crop or forest product). Where it is appropriate to include a value for emissions from leakage, such an estimate should be included when possible. Development of a methodology for calculating leakage, or assessing potential values from existing work for use in this framework, is beyond the scope of this report. We note, however, that emissions from leakage can be significant. For example, if we consider a situation in which merchantable wood is diverted from the market such that demand for additional wood for bioenergy is met from pulp-producing regions in Canada, we might use the data reported by McKechnie et al. (2011), who found that additional harvest in forests in Ontario for electricity production release 1.9 to 4.3 metric tons of CO_2e per MWh generated. Therefore, an average leakage effect might be 3.1 tCO_2e per MWh generated (average of the above range). Since this case-study assumes that the plant uses 1 BDT of wood per MWh, in Step 4 for this case study, we might calculate leakage in terms of emissions occurring outside the accounting system boundary as follows:
LEAK = [(1.9 + 4.3 CO_2e per MWh)/ 2) × 1 MWh per BDT × 250,000 BDT] = 775,000 tCO_2 e At the same time, we note that quantification of specific leakage values across industries is a subject of debate, and depends on multiple interacting factors for each situation.

Case 1: Existing facility with either New Hampshire or the Northeast Region defined as the feedstock source region:

$$\text{NBE} = [415{,}800 \times (1 + 0) \times (1 - 1) \times (1 - 0)] - [415{,}800 \times 0] + [0 \times (1 - 0)] + [0 \times (1 - 0)]$$

$$\text{NBE} = 0 \text{ tCO}_2\text{e}$$

Case 2: Proposed new facility, with the Northeast Region defined as the feedstock source region:

$$\text{NBE} = [415{,}800 \times (1 + 0) \times (1 - 1) \times (1 - 0)] - [415{,}800 \times 0] + [0 \times (1 - 0)] + [0 \times (1 - 0)]$$

$$\text{NBE} = 0 \text{ tCO}_2\text{e}$$

Case 3: Proposed new facility, with New Hampshire defined as the feedstock source region:

$$\text{NBE} = [415{,}800 \times (1 + 0) \times (1 - 0.2507) \times (1 - 0)] - [415{,}800 \times 0] + [0 \times (1 - 0)] + [0 \times (1 - 0)]$$

$$\text{NBE} = 311{,}559 \text{ tCO}_2\text{e}$$

Step 6: Biogenic Accounting Factor (BAF)

As defined in the accounting framework (Glossary), the Biogenic Accounting Factor (BAF) is the fraction of PGE that becomes a net biogenic CO_2 emission to the atmosphere. Thus:

$$\text{BAF} = \text{NBE} / \text{PGE}$$

Case 1: Existing facility with either New Hampshire or the Northeast Region defined as the feedstock source region:

$$\text{BAF} = 0 \text{ tCO}_2\text{e} / 415{,}800 \text{ tCO}_2\text{e}$$

$$\text{BAF} = 0$$

Case 2: Proposed new facility, with the Northeast Region defined as the feedstock source region:

$$\text{BAF} = 0 \text{ tCO}_2\text{e} / 415{,}800 \text{ tCO}_2\text{e}$$

$$\text{BAF} = 0$$

Case 3: Proposed new facility, with New Hampshire defined as the feedstock source region:

$$\text{BAF} = 311{,}559 \text{ tCO}_2\text{e} / 415{,}800 \text{ tCO}_2\text{e}$$

$$\text{BAF} = 0.7493$$

Table 1: Numeric Results of the Net Biogenic Emissions Equation Variables

Variable	Values			Units
	Case 1	Case 2	Case 3	
Net Biogenic Emissions (NBE)	0	0	311,559	tCO_2e
Potential Gross Emissions (PGE)	415,800	415,800	415,800	tCO_2e
Level of Atmospheric Reduction (LAR)	1	1	0.2507	Proportion (no units)
Carbon in Products (PRODC)	0	0	0	Proportion (no units)
Sequestered Fraction (SEQP)	0	0	0	Proportion (no units)
Net emissions gain on site (SITE_TNC)	0	0	0	tCO_2e
Leakage (LEAK)	0	0	0	Proportion (no units)
Proportion of Feedstock Lost (L)	0	0	0	Proportion (no units)
Biogenic Accounting Factor (BAF)	0	0	0.749	Proportion (no units)

Summary

This case illustrates the influence of the definition of the feedstock source region on the calculation of net biogenic emissions (NBE). It also highlights how results can differ when the framework is applied to new versus proposed electric generating facilities using roundwood harvested from forests Delineation of source regions for forest-based feedstocks will be a critical step in developing a full accounting framework[50], and will ultimately reflect both policy and technical considerations. One or more large new facilities (PGE > 500,000 tCO_2e/yr) could exceed the current sequestration rates of available forestland in many states, and some states are currently experiencing declines in carbon stocks. Accounting at the regional level could thus mask smaller-scale changes in carbon stocks, especially if some states are experiencing large increases or decreases in carbon stocks.

Additional Information

Additional information about this case-study scenario is provided in three Tables below. Table 2 contains a more detailed summary of the features of the case study. Table 3 contains key data inputs and assumptions used in the calculations. Table 4 presents data from USDA Forest Service for calculation of change in forest carbon stocks for private timberland in the Northeast region (Maine to West Virginia) and the state of New Hampshire, across all tree species.

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[50] As stated in Section 4, the exact size of a region is not prescribed in this framework. Specific regions would be defined as a matter of policy, but the appropriate size and regional boundaries could depend on multiple factors, including but not limited to economic and market characteristics, biophysical characteristics, and data availability

Table 2: Information about the case study parameters

System Variable	Description
Feedstock type	• Roundwood: 100% • Total feedstock: 250,000 bone dry tons/year • All owners, all species
Feedstock source locations	• Region: Northeast (Maine to West Virginia) • State: New Hampshire
Facility description	• Energy fate: Electricity • Example facility size: 30 MW (95% efficiency) • Example facility location: Northeast
Land-use change	• Prior, current and future land use: Unreserved timberland • Sequestration with forest production: Gain relative to forest growth • Management scenario: Unspecified
Feedstock loss	• Conveyance/Haulage: 0% of feedstock carbon produced • Storage: 0% of feedstock carbon produced • Pre-processing/Drying: 0% of feedstock carbon produced
Sequestered Fraction/ Carbon in Products	• Sequestered Fraction: 0% (assumed full combustion) • Products: None
Feedstock characteristics	• Carbon content: 0.50 carbon content per dry ton (Roundwood) • Mass of feedstock: 250,000 dry tons of wood per year (Roundwood)
Baseline	• Current land use: Unreserved forest land (timberland as defined by FIA.) • Effects of alternative land use: None
Years for annualizing growth and sequestration changes	• Concurrent year's growth in associated unreserved timberland carbon stocks
Leakage	• Market affected based on type and amount of wood used for energy feedstock: Not calculated

Table 3: Key inputs and assumptions for case study calculations

Key Inputs	Values	Units	Notes
	Northeast		
Feedstock needed	250,000	Bone dry tons/year	None
Carbon Content of feedstock	0.50	Carbon content/oven-dry ton	Amount of carbon in a dry ton of feedstock
Storage Losses	0	Percentage of feedstock needed	Assumed carbon loss in storing wood to time of consumption
Handling and transport losses	0	Percentage of feedstock needed	Assumed carbon loss in moving wood to point of consumption and 0% losses in plant
Yield per acre	25 to 100	Yield of wood per acre of land in wet tons	Number for "yield per acre" could range from 25 to 100 based on the make-up of the non-merchantable feedstock, i.e., if the feedstock only consists of biomass from limbs, tops, and non-merchantable species and/or sizes the yield per acre is lower (25) than if low-grade logs are included (in the absence of a pulpwood market), and the feedstock needed can be sourced from fewer acres
Years for annualizing growth and sequestration	1	Year	It is assumed that the wood is sustainably harvested, and all of it is replaced in a year

Key Inputs	Notes
Calculating PGE	Standard calculation where carbon is a fixed percent of a dry ton
Calculating SEQP	Assumes zero—corresponds to complete combustion
Calculating SITE_TNC	In this example, with no change in land use and no known change in total forest capacity due to the harvesting; set to zero
Calculating LEAK	None computed; set to zero

Table 4: Data for calculation of change in forest carbon stocks for private timberland, all species

Inputs to LAR	Landscape		
	NE	NH	Source
Net growth of all live on timberland (cu ft/yr)	3,840,035,380	177,443,028	USFS
Net growth of all live on timberland (tCO_2e/yr)	99,689,392	4,606,517	Calculated
All removals on timberland (cu ft/year)	2,411,203,698	174,695,058	USFS
All removals on timberland (tCO_2e/year)	62,596,150	4,535,178	Calculated
Net change in tree biomass on timberland (OD short tons)	36,357,722	62,667	USFS
Net change in tree biomass on timberland (tCO_2e)	60,484,044	104,252	Calculated

Note that the USDA-FS data are presented in either cu ft/yr of annual growth or OD short tons of net change. All of these data must be converted to tCO_2e before they can be compared to the Potential Gross Emissions of the proposed power plant.

References

U.S.D.A. Forest Service (2011). Department of Agriculture. "FIADB4 Population Estimates." Accessed from: http://apps.fs.fed.us/fiadb-downloads/FIADB4_pop_estimates.html. Last updated July 9, 2011.

McKechnie J, Colombo S, Chen J, Mabee W, and MacLean HL (2011). "Forest bioenergy or forest carbon? Assessing trade-offs in greenhouse gas mitigation with wood-based fuels." Environ. Sci. Technol. 45(2):789-95.

Case Study 2: Calculating Net Biogenic Emissions from Electricity Generation Using Roundwood Harvested in the Northeast United States, Comparing the Average versus Marginal Method for Level of Atmospheric Reduction

Description

As discussed in Sections 3.9.E and 4.9.B of the report, there is an important policy decision to make about attributing responsibility in forestry cases where carbon stocks are declining. These have been termed the "Average" and "Marginal" methods for calculating the Level of Atmospheric Reduction (LAR) term. The accounting framework itself does not make a determination on this issue but rather highlights the considerations related to this issue for any future program and policy application. This case study shows how both approaches could be applied.

In the Average Method of calculating LAR, feedstock consumption from a given facility is added to the total feedstock consumption for energy production from a given source region, and an individual facility is only charged with the portion of the total feedstock harvest it consumes. This differs from the Marginal Method where the stationary source is charged with the entire amount of any removals that exceed net growth. The differences between the two methods will be influenced by the size of landscape chosen for the analysis (i.e., Northeast region versus New Hampshire state, see Case Study 1) and are illustrated in this case study. Also note that if the feedstock is sourced from a landscape with an increasing stock of carbon, both the Average and Marginal Methods result in a calculation of LAR = 1 (i.e., all feedstock is assumed to be replaced by net growth in the source region).

This case study begins with the general features of Case Study 1, and illustrates the calculation of net biogenic CO_2 emissions when the Average Method is substituted for the Marginal Method for calculation of LAR.

Essential Features

This example assumes conditions similar to Case Study 1, but considers only a proposed new facility (rather than both existing and proposed facilities):

- a proposed plant with an output of 30 megawatts (MW) per year, that is designed to run at 95 percent efficiency, converts 1 bone dry ton (BDT) of wood per megawatt-hour (MWh) of electricity produced, and would consume an input of 250,000 BDT of wood per year,
- the feedstock is sourced from harvest of low-grade roundwood, and does not compete with traditional timber and pulp markets, and
- there are no other forest-derived woody sources (e.g., mill byproducts, urban tree removals, logging residues) used as feedstocks for the hypothetical plant.

Overview

The accounting framework formula for Net Biogenic Emissions (NBE) is (Eqn. 3, Section 5.1 of the accounting framework):

$$\begin{aligned} NBE = {} & [PGE \times (1 + L) \times (1 - LAR) \times (1 - PRODC)] \\ & - [PGE \times SEQP] \\ & + [SITE\_TNC \times (1 - PRODC)] \\ & + [LEAK \times (1 - PRODC)] \end{aligned}$$

The following sections describe calculation of Net Biogenic Emissions (NBE) and the Biogenic Accounting Factor (BAF) in six steps:

Step 1: Potential Gross Emissions (PGE), feedstock carbon lost along supply chain (L), Level of Atmospheric Reduction (LAR), and carbon leaving the accounting framework as products (PRODC)
Step 2: Carbon storage resulting from incomplete utilization (SEQP)
Step 3: Carbon Emissions/Sequestration at the Feedstock Production Site (SITE_TNC)
Step 4: Leakage (LEAK)
Step 5: Net Biogenic Emissions (NBE)
Step 6: Biogenic Accounting Factor (BAF)

Step 1: Potential Gross Emissions (PGE), feedstock carbon lost along supply chain (L), Level of Atmospheric Reduction (LAR), and carbon leaving the accounting framework as products (PRODC)

Step 1 begins with a calculation of the carbon that is contained in the feedstock as it leaves the farm gate or forest (Potential Gross Emissions or PGE). Note that in this case, PGE is calculated with reference to the feedstock that is used by the facility, and then the proportion that is lost in transport, storage and handling (L) is added, in order to find the actual quantity of feedstock that must be produced on the land to support a particular facility's feedstock utilization.

i. *Calculating Potential Gross Emissions (PGE)*

Potential Gross Emissions (PGE) are the metric tons of CO_2e that could potentially be released from the stationary source stack. PGE is the product of the mass of feedstock used by the facility and its carbon content. Conversion factors are used to express the PGE as metric tons CO_2e. See Table 3 for the values for each of the coefficients in this case study.

$$PGE = (\text{Feedstock needed})^{51} \times (\text{Carbon content of feedstock}) \times \text{English to Metric tons} \times \text{Carbon to } CO_2e$$

$$PGE = (250{,}000) \times 0.5 \times 0.9072 \times (44 / 12)$$

$$PGE = 415{,}800\ tCO_2e$$

- #### *Calculating Proportion of Feedstock Lost (L)*

In this case study, feedstock losses between forest and facility are assumed to be negligible, and thus L=0.

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[51] "Feedstock needed" refers to the amount of feedstock consumed by the facility, and could be quantified as actual (in the case of an existing facility) or projected (in the case of a new facility) consumption.

- ***Calculating Level of Atmospheric Reduction (LAR)***

Level of Atmospheric Reduction (LAR) is the proportional atmospheric CO_2e reduction that results from either (a) feedstock growth and sequestration of atmospheric CO_2 (GROW), or (b) avoided emissions (AVOIDEMIT) that would have contributed to atmospheric CO_2e when the material decomposed (for details, see Eqn. 6, Section 5.2.C of the Accounting Framework).

The basic equation for LAR specifies the degree to which gross emissions (plus loss) are offset by feedstock growth and any avoided emissions:

$$\text{LAR} = (\text{GROW} + \text{AVOIDEMIT}) \,/\, (\text{PGE}) \times (1 + \text{L}))$$

Note that avoided emissions are not relevant for this case study as there are no residue-based feedstocks used by the proposed generating facility.

When forest feedstock demand exceeds supply from a region, forest carbon stocks will decline, and there will likely be positive (non-zero) net biogenic emissions from the aggregate use of those feedstocks. As described in Sections 3.9.E and 4.9.B of the accounting framework, there are different ways of apportioning responsibility for those net emissions among forest feedstock users.

The accounting framework presents two alternatives, based on different methods of calculation of LAR: (1) the Marginal Method (used in Case Study 1), in which new facilities are responsible for any net emissions due to a shortfall in net growth relative to feedstock consumption, and (2) the Average Method (using an example equation generated for this case study only), in which the shortfall is apportioned among all consumers of forest biomass from that region in proportion to their use.

Case 1: Northeast Region—In this case, since the region has increasing stocks of forest biomass, and the feedstock demand from the proposed facility is significantly less than the current annual increase in forest biomass (sequestration), both the Marginal and Average methods yield the same result for LAR.

<u>Marginal or Average Method:</u>

GROW = Annual Sequestration (Net annual change in tree biomass on timberland) = 60,484,044 tCO_2e

[PGE × (1 + 0)] = PGE = 415,800 tCO_2e

LAR = 1 (i.e., region can absorb the new feedstock consumption and still have a positive net gain in forest biomass)

Case 2: State of New Hampshire—In this case, the proposed annual demand from the new facility would exceed the current annual rate of increase in forest biomass for the source region (the state of New Hampshire). Both the Marginal and Average Methods result in a calculation that LAR < 1 (i.e., not all of the Potential Gross Emissions are offset by feedstock growth). But the two methods differ in how they apportion the degree to which potential gross emissions from the proposed facility are offset by the limited forest growth.

<u>Marginal Method:</u>

GROW = Annual Sequestration (Net annual change in tree biomass on timberland) = 104,252 tCO_2e

[PGE × (1 + 0)] = PGE = 415,800 tCO_2e

LAR = 104,252 tCO_2e /415,800 tCO_2e

LAR = 0.2507 (i.e., 25.07% of PGE is offset by feedstock growth)

In the Marginal Method the bioenergy plant is responsible for all of the Potential Gross Emissions (PGE) that push a region or state's carbon stocks into decline. Put another way, this assumes that 104,252 tCO_2e of PGE (representing annual sequestration) have an LAR of 1, and the remaining 311,548 tCO_ee of PGE have an LAR of 0, giving a weighted average LAR of 0.2507.

Average Method:

According to the Average Method of estimating LAR (shown below), in regions where, in this case, feedstock consumption by the new facility would push carbon stocks into decline, the resulting shortfall between total biomass harvest and regional net growth would be apportioned among all consumers of forest biomass. Thus, the new facility is responsible for a much smaller share of those regional net emissions. Calculation of LAR under the Average Method requires additional data, specifically, estimates of the net growth of forest biomass for the region, and total removals of biomass (for all uses). Both of these estimates can be derived from FIA data (see Table 4).

Using the Average method for the present example:

Annual demand from the proposed bioenergy plant (Facility Demand) =)= 415,800 tCO_2e

Present total annual harvest from forestland (Present Harvest, Table 4) = 4,535,178 tCO_2e

Total projected annual removals from forestland (Present Harvest + Facility Demand) = 4,950,978 tCO_2e

Current net growth on forestland (Table 4) = 4,606,517 tCO_2e

Under the Average Method utilized in this case study, LAR is then estimated by:

LAR = (Current Net Growth) / (Present Harvest + Facility Demand)

LAR = 4,606,517 tCO_2e / (4,535,178 + 415,800) tCO_2e

LAR = 0.9304 (i.e., 93.04% of PGE is offset by feedstock growth)

- ***Calculating Carbon in Products (PRODC)***

Carbon in Products (PRODC) is the carbon content in products, in terms of CO_2e, made from processing of the biogenic feedstocks, including energy products like ethanol and lignin that are combusted (or used) elsewhere (outside the stationary source), as well as non-energy products like DDGS or lumber that are used elsewhere. In this case study, there is no Carbon in Products as the hypothetical electric generating facility does not produce other commercial products. Thus, PRODC = 0.

- *Step 1: Conclusion*

In this first step, PGE is adjusted for feedstock losses (L) and Level of Atmospheric Reduction (LAR):

$$PGE \times (1 + L) \times (1 - LAR)$$

Case 1: Northeast Region

Marginal/Average:

$$415{,}800\ tCO_2e \times (1 + 0) \times (1 - 1) = 0\ tCO_2e$$

Case 2: New Hampshire State

Marginal:

$$415{,}800\ tCO_2e \times (1 + 0) \times (1 - 0.2507) = 311{,}559\ tCO_2e$$

Average:

$$415{,}800\ tCO_2e \times (1 + 0) \times (1 - 0.9304) = 28{,}940\ tCO_2e$$

Step 2: Carbon storage resulting from incomplete utilization (SEQP)

Step 2 calculates the difference between what could be emitted by utilization of the feedstock (PGE) when combusted fully and what is actually emitted as a result of the production of a Sequestered Fraction (SEQP) in the form of post-combustion material. This term can include carbon sequestered in residuals like ash or carbon sequestered through carbon capture technology. Note that if these materials are sold for use outside the stationary source rather than disposed of, they should be counted in PRODC.

The Sequestered Fraction (SEQP) is the proportion of the feedstock carbon content that is contained in the derivative products that remain after biogenic feedstock combustion at the stationary source. In some production technologies, virtually all of the carbon in the feedstock is emitted as CO_2. In that event, SEQP would be 0 or very close to 0. In other technologies, unburned carbon is left in the ash.

$$SEQP = CO_2e \text{ sequestered from stationary source} / PGE$$

This case study assumes full combustion and consequently no Sequestered Fraction.

$$SEQP = 0\ tCO_2e / 415{,}800\ tCO_2e = 0$$

And thus,

$$[PGE \times SEQP] = 415{,}800\ tCO_2e \times 0 = 0\ tCO_2e$$

Step 3: Carbon emitted from the site where feedstock was grown/collected (SITE_TNC)

The SITE_TNC term accounts for changes in the stock of land-based carbon (above and below ground) that may result from changes in land-use and land management associated with feedstock production. In the case of forest-derived feedstocks, the SITE_TNC term would be used to account for any net change in forest carbon stocks that might occur as a result of, for example, intensification of harvest practices (e.g., due to use of harvest residues). See Section 5.2.F of the accounting framework for details.

The SITE_TNC term has two components: Change in Net Site Emissions (SITEEMIT), (positive when harvest practices or land-use change result in a long-term net increase in CO_2 emissions from the land relative to what would happen in the absence of harvest), and Change in Net Site Sequestration (SITESEQ) (positive when harvest practices or land-use change result in a long-term net increase in CO_2 sequestration on the land relative to what would happen in the absence of harvest):

$$\text{SITE\_TNC} = \text{SITEEMIT} - \text{SITESEQ}$$

This case study assumes that feedstock was sourced from managed timberland, using established harvesting methods, and thus assumes that there are no changes in site CO_2 emissions or sequestration as a result of the feedstock production.

Thus SITEEMIT, SITESEQ and SITE_TNC are 0.

Step 4: Leakage (LEAK)

Step 4 of the NBE formula accounts for effects of leakage or indirect land-use change. Specifically, LEAK is the leakage of biogenic carbon emissions generated outside the supply chain induced by market reactions to biogenic feedstock use for bioenergy (i.e., replacement of diverted crop, livestock or forest products due to a change in land use from conventional products to biomass feedstocks). The term is expressed as net emissions of metric tons CO_2e that occur when producing the feedstock volume needed for stationary combustion.

Since this case study assumes that no marketable wood was diverted from the market for traditional forest products into bioenergy, LEAK is assumed to be 0.

Step 5: Net Biogenic Emissions (NBE)

The calculation of Net Biogenic Emissions (NBE) combines the terms calculated in Steps 1–4:

$$\begin{aligned} \text{NBE} = {} & [\text{PGE} \times (1 + \text{L}) \times (1 - \text{LAR}) \times (1 - \text{PRODC})] \\ & - [\text{PGE} \times \text{SEQP}] \\ & + [\text{SITE\_TNC} \times (1 - \text{PRODC})] \\ & + [\text{LEAK} \times (1 - \text{PRODC})] \end{aligned}$$

Case 1: Northeast region

Marginal/Average:

$$\text{NBE} = [415{,}800 \times (1 + 0) \times (1 - 1) \times (1 - 0)] - [415{,}800 \times 0] + [0 \times (1 - 0)] + [0 \times (1 - 0)]$$

$$\text{NBE} = 0\ tCO_2 \text{ per year}$$

Case 2: New Hampshire

Marginal:

$$\text{NBE} = [415{,}800 \times (1 + 0) \times (1 - 0.25) \times (1 - 0)] - [415{,}800 \times 0] + [0 \times (1 - 0)] + [0 \times (1 - 0)]$$

$$\text{NBE} = 311{,}559 \text{ tCO}_2\text{e}$$

Average:

$$\text{NBE} = [415{,}800 \times (1 + 0) \times (1 - 0.930) \times (1 - 0)] - [415{,}800 \times 0 + 0 \times (1 - 0)] + [0 \times (1 - 0)]$$

$$\text{NBE} = 28{,}940 \text{ tCO}_2\text{e}$$

Step 6: Biogenic Accounting Factor (BAF)

As defined in the accounting framework (Glossary), the Biogenic Accounting Factor (BAF) is the fraction of PGE that becomes a net biogenic CO_2 emission to the atmosphere. Thus:

$$\text{BAF} = \text{NBE} \ / \ \text{PGE}$$

Case 1: Northeast region

Marginal/Average:

$$\text{BAF} = 0 \text{ tCO}_2\text{e} / 415{,}800 \text{ tCO}_2\text{e} = 0$$

Case 2: New Hampshire

Marginal:

$$\text{BAF} = 311{,}559 \text{ tCO}_2\text{e} / 415{,}800 \text{ tCO}_2\text{e} = 0.7493$$

Average:

$$\text{BAF} = 28{,}940 \text{ tCO}_2\text{e} / 415{,}800 \text{ tCO}_2\text{e} = 0.0696$$

Table 1: Numeric results of the Net Biogenic Emissions Equation Variables under Marginal and Average Methods for LAR Estimation

Variable	Northeast		New Hampshire		Units
	Marginal	Average	Marginal	Average	
Net Biogenic Emissions (NBE)	0	0	311,559	28,940	tCO_2e
Potential Gross Emissions (PGE)	415,800	415,800	415,800	415,800	tCO_2e
Level of Atmospheric Reduction (LAR)	1	1	0.2507	0.9304	Proportion (no units)
Carbon in Products (PRODC)	0	0	0	0	Proportion (no units)
Sequestered Fraction (SEQP)	0	0	0	0	Proportion (no units)
Net emissions gain on site (SITE_TNC)	0	0	0	0	tCO2e
Leakage (LEAK)	0	0	0	0	Proportion (no units)
Proportion of Feedstock Lost (L)	0	0	0	0	Proportion (no units)
Biogenic Accounting Factor (BAF)	0	0	0.749	0.070	Proportion (no units)

[a] Numbers for Acres Needed (ACRES) could range from 20,000 acres to 5,000 acres based on the make-up of the non-merchantable feedstock, i.e., if low-grade logs are included (in the absence of a pulpwood market) the feedstock needed can be sourced from fewer acres (5,000 acres here) than if the feedstock only consists of biomass from limbs, tops, and non-merchantable species and/or sizes (20,000 acres here).

Summary

This case study highlights the differences in calculation of net biogenic emissions (NBE) under different methods for apportioning emissions when demands on forest feedstocks exceed supply within a source region. While the example here considered only the case of a proposed new facility, similar issues exist with respect to estimating NBE for existing facilities when carbon stocks are declining within a source region. It is important to note that both net growth and overall harvest of forest biomass can vary significantly over time. The FIA data used in this case study are from the period from 2002 to 2008, when demand for forest products was high. In 2009, demand fell and many mills closed. More recent data are likely to show lower annual forest removals, which will affect the LAR (and NBE) calculation significantly.

Additional Information

Additional information about this case-study scenario is provided in three Tables below. Table 2 contains a more detailed summary of the features of the case study. Table 3 contains key data inputs and assumptions used in the calculations. Table 4 presents data from USDA Forest Service for calculation of change in forest carbon stocks for private timberland in the Northeast region (Maine to West Virginia) and the state of New Hampshire, across all tree species.

Table 2: Information about the case study parameters

System Variable	Description
Feedstock type	• Roundwood: 100% • Total feedstock: 250,000 bone dry tons/year • All owners, all species
Feedstock source locations	• Region: Northeast (Maine to West Virginia) • State: NH
Facility description	• Energy fate: Electricity • Example facility size: 30 MW (95% efficiency) • Example facility location: Northeast
Land-use change	• Prior, current and future land use: Unreserved timberland • Sequestration with forest production: Gain relative to forest growth • Management scenario: Unspecified
Feedstock loss	• Conveyance/Haulage: 0% of feedstock carbon produced • Storage: 0% of feedstock carbon produced • Pre-processing/Drying: 0% of feedstock carbon produced
Sequestered Fraction/ Carbon in Products	• Sequestered Fraction: 0% (assumed full combustion) • Products: None
Feedstock characteristics	• Carbon content: 0.50 carbon content per dry ton (Roundwood) • Mass of feedstock: 250,000 dry tons of wood per year (Roundwood)
Baseline	• Current land use: Unreserved forestland • Effects of alternative land use: None
Years for annualizing growth and sequestration changes	• Concurrent year's growth in associated unreserved timberland carbon stocks
Leakage	• Market affected based on type and amount of wood used for energy feedstock: Not calculated

Table 3: Key inputs and assumptions for case study calculations

Key Inputs	**Values** **Northeast**	**Units**	**Notes**
Feedstock needed	250,000	Bone dry tons/year	
Carbon Content of feedstock	0.50	Carbon content/oven-dry ton	Amount of carbon in a dry ton of feedstock
Storage Losses	0	Percentage of feedstock needed	Assumed carbon loss in storing wood to time of consumption
Handling and transport losses	0	Percentage of feedstock needed	Assumed carbon loss in moving wood to point of consumption and 0% losses in plant
Yield per acre	25 to 100	Yield of wood per acre of land in wet tons	Number for "yield per acre" could range from 25 to 100 based on the make-up of the non-merchantable feedstock, i.e., if the feedstock only consists of biomass from limbs, tops, and non-merchantable species and/or sizes the yield per acre is lower (25) than if low-grade logs are included (in the absence of a pulpwood market) and the feedstock needed can be sourced from fewer acres
Years for annualizing growth and sequestration	1	Years	It is assumed that the wood is sustainably harvested and all of it is replaced in a year

Key Inputs	**Notes**
Calculating PGE	Standard calculation where carbon is a fixed percent of a dry ton
Calculating SEQP	Assumes zero—corresponds to complete combustion
Calculating SITE_TNC	In this example, with no change in land use and no known change in total forest capacity due to the harvesting; set to zero
Calculating LEAK	None computed; set to zero

Table 4: Data for calculation of change in forest carbon stocks for private timberland, all species

Inputs to LAR	**Landscape**		
	NE	**NH**	**Source**
Net growth of all live on timberland (cu ft/yr)	3,840,035,380	177,443,028	USFS
Net growth of all live on timberland (tCO_2e/yr)	99,689,392	4,606,517	Calculated
All removals on timberland (cu ft/year)	2,411,203,698	174,695,058	USFS
All removals on timberland (tCO_2e/year)	62,596,150	4,535,178	Calculated
Net change in tree biomass on timberland (OD short tons)	36,357,722	62,667	USFS
Net change in tree biomass on timberland (tCO_2e)	60,484,044	104,252	Calculated
PGE (new harvest for 30 MW plant) (tCO_2)	415,800	415,800	Calculated
New harvest + average annual removals = total annual harvest	63,012,060	4,951,088	Calculated
New harvest as % of total annual harvest	0.7%	8.4%	Calculated
New harvest as % of annual net change	0.7%	398.9%	Calculated

Note that the USDA-FS data are presented in either cu ft/yr of annual growth or OD short tons of net change. All of these data must be converted to tCO_2e before they can be compared to the Potential Gross Emissions of the proposed power plant.

References

U.S.D.A. Forest Service (2011). Department of Agriculture. "FIADB4 Population Estimates." Accessed from: http://apps.fs.fed.us/fiadb-downloads/FIADB4_pop_estimates.html. Last updated July 9, 2011.

Case Study 3: Calculating Net Biogenic Emissions for a Pulp and Paper Mill Harvesting Roundwood in the Pacific Northwest

Description

This case study provides an illustration of net biogenic CO_2 emissions for a biomass cogeneration plant at a pulp and paper mill in the state of Washington. This case study illustrates how biomass energy may play a subservient role in the facility. In the case of pulp and paper mills, woody biomass is purchased primarily for the production of paper products for printing, packaging, or other markets. Because of the high energy demands of the pulping and papermaking process and the ready availability of mill residues and byproducts (such as black liquor), such mills usually produce a substantial portion of their energy needs through biomass burning. The results for this case study are shown in Table 1.

Essential Features

- The pulp and paper mill in this scenario purchases wood from two sources: forests (300,000 tons per year) and byproducts such as chips and sawdust from other wood-processing facilities such as sawmills (100,000 tons per year).
- Both feedstocks are sourced from within the state of Washington.
- From the 2007 RPA assessment (Smith et al., 2009), Washington State had net growth of 1,638,148 thousand cubic feet of forest and removals of 899,047 thousand cubic feet. This equates to net growth of 32.1 million dry tons biomass and removals of 17.6 million dry tons biomass. Thus, harvest of 0.3 million tons of biomass for paper and energy production in this case study will be replaced by growth in this region. This assumes the entire state is the sourcing region for the mill; while clearly this would not be the case, the excess growth statewide is so high that these statewide numbers make the case that harvests will not put forest carbon stocks in the region into decline.
- These two feedstocks provide the wood fiber needed for all mill operations. These feedstocks are blended in the mill prior to manufacture of pulp and paper and energy production, so they share common factors such as losses, product proportions, etc.
- The mill uses residues from this purchased wood biomass for pulp production as well as byproducts such as black liquor to fire a boiler that produces steam for electricity generation and to provide heat for the pulping process.
- The electricity generation from biomass is equivalent to about 35 MW. Fossil fuels are also used in the mill for energy, but are not included in these calculations.
- See Table 2 for additional information about the parameters used in this case study.

Overview

The following sections describe calculation of Net Biogenic Emissions (NBE) and the Biogenic Accounting Factor (BAF) in six steps:

Step 1: Potential Gross Emissions (PGE), feedstock carbon lost along supply chain (L), Level of Atmospheric Reduction (LAR), and carbon leaving the accounting framework as products (PRODC)
Step 2: Carbon storage resulting from incomplete utilization (SEQP)
Step 3: Carbon Emissions/Sequestration at the Feedstock Production Site (SITE_TNC)
Step 4: Leakage (LEAK)
Step 5: Net Biogenic Emissions (NBE)
Step 6: Biogenic Accounting Factor (BAF)

Overview

As presented in Section 4 of the accounting framework, the complete formula for estimating Net Biogenic Emissions (NBE) is:

$$\begin{aligned} \text{NBE} = & [\text{PGE} \times (1 + \text{L}) \times (1 - \text{LAR}) \times (1 - \text{PRODC})] \\ & - [\text{PGE} \times \text{SEQP}] \\ & + [\text{SITE\_TNC} \times (1 - \text{PRODC})] \\ & + [\text{LEAK} \times (1 - \text{PRODC})] \end{aligned}$$

In each of the Steps 1 through 4, we work through the calculations required for the square-bracketed terms.

Step 1: Potential Gross Emissions (PGE), feedstock carbon lost along supply chain (L), Level of Atmospheric Reduction (LAR), and carbon leaving the accounting framework as products (PRODC)

In Step 1, the difference between what could potentially be emitted if all of the feedstock produced is consumed, and what is actually emitted as a result of the feedstock processing or combustion process is calculated. It is then adjusted for the amount of carbon contained in products that ultimately leave the source and thus occur outside the accounting framework. This Step corresponds to the following term, which appears first in the full Net Biogenic Emissions (NBE) equation above:

$$[\text{PGE} \times (1 + \text{L}) \times (1 - \text{LAR}) \times (1 - \text{PRODC})]$$

The calculation begins with the carbon that is contained in the feedstock as it leaves the production site (e.g., farm, forest). Note that PGE is calculated with reference to the feedstock that is used by the facility. The proportion that is lost in transport, storage and handling (L) is added, in order to find the actual quantity of feedstock that must be produced at the production site to provide feedstock for the facility.

i. Calculating Potential Gross Emissions (PGE)

Potential Gross Emissions (PGE) refers to the metric tons of CO_2e contained in the feedstock as it enters the source—in other words, it is the total CO_2e that could potentially be released. PGE is the product of the mass of feedstock used by the facility and its carbon content. Conversion factors are used to express the final PGE as metric tons CO_2e. See Table 3 for default values for each of the coefficients. Note that in this case, the feedstock input to the source is measured in English units, so the conversion from English to Metric is necessary.

$$\begin{aligned} \text{PGE} = {} & (\text{Feedstock needed}) \\ & \times (\text{Carbon content of feedstock}) \\ & \times \text{English\_to\_Metric} \\ & \times \text{Carbon to } CO_2e \end{aligned}$$

Wood from forests:

$$\text{PGE} = 300{,}000 \text{ tons per year} \times 0.5 \times 0.9072 \times (44 / 12) = 498{,}960 \text{ tCO}_2 \text{ per year}$$

Residues from mills:

$$\text{PGE} = 100{,}000 \text{ tons per year} \times 0.5 \times 0.9072 \times (44 / 12) = 166{,}320 \text{ tCO}_2 \text{ per year}$$

Combined:

$$\text{PGE} = 498{,}960 \text{ tCO}_2 \text{ per year} + 166{,}320 \text{ tCO}_2 \text{ per year}$$

$$\text{PGE} = 665{,}280 \text{ tCO}_2 \text{ per year}$$

- ***Calculating Proportion of Feedstock Lost (L)***

Feedstock Lost (L) is the proportion of additional feedstock production needed to overcome loss in conveyance, storage, and plant handling. The following equations give the amount of potential emissions in the feedstock that must be produced (TFP) at the feedstock site.

This case study uses data from Côté et al. (2002) on feedstock losses, simply as an example. Process studies of a pulp and paper mill would indicate steps in the process in which losses occur, and proportions of those losses. In the example documented by Côté et al. (2002), an annual feedstock of 641,000 tons (Carbon content) was subject to losses of 29,000 tons in debarking and processing (0.0452 of the feedstock), and 21,000 tons in the bleaching process (0.0328 of the feedstock). There were no storage losses. Thus, the total loss of 50,000 tons out of 641,000 tons represents a loss fraction of 7.95%. Thus, L is 0.0795 for this example.

$$\begin{aligned} \text{TFP} = {} & (\text{Feedstock needed}) \\ & \times (1 + \text{Plant Losses}) \\ & \times (1 + \text{Storage Losses}) \\ & \times (1 + \text{Losses during handling and transport}) \end{aligned}$$

and

$$L = (\text{TFP} / \text{Feedstock needed}) - 1$$

$$\text{TFP} = 400{,}000 \times (1 + .0328) \times (1 + 0) \times (1 + .0452) = 431{,}793.02$$

and

$$L = (431{,}793.02 / 400{,}000) - 1 = 0.0795$$

These loss proportions are applied equally to the wood from forest feedstock and the residue from mills feedstock.

- *Calculating Level of Atmospheric Reduction (LAR)*

Level of Atmospheric Reduction (LAR) is the proportional atmospheric CO_2e reduction that is associated with either: (a) feedstock growth, which sequesters atmospheric CO_2 (GROW), or (b) avoided emissions (AVOIDEMIT) from the biogenic feedstock (e.g., from decomposition of forestry and agricultural residues), which would otherwise have contributed to atmospheric CO_2e.

When LAR equals one all the emissions are offset. When it equals zero none are offset. A term between 0 and 1 means some proportion is offset. The following equation gives the amount that is offset by growth or avoided emissions.

$$\text{LAR} = (\text{GROW} + \text{AVOIDEMIT}) / (\text{Feedstock needed} \times (1 + L))$$

$$\text{Net Change in Forest Biomass} = \text{Annual Net Growth} - \text{Annual Removals}$$

$$\begin{aligned}\text{Annual Growth or Annual Removals} &= \text{Volume} / \text{cubic feet per dry ton}\\ &\times \text{Carbon to } CO_2e\\ &\times \text{English\_to\_Metric}\end{aligned}$$

For wood from forests, LAR = 1 if feedstocks are replaced (i.e., net change in forest biomass is positive); 0 if not. From FIA data for the state of Washington:

$$\begin{aligned}\text{Annual net growth} &= (1638.148 \text{ million cubic feet} / 51.05 \text{ cubic feet per dry ton})\\ &\quad \times 0.9072 \times (44 / 12)\\ &= 106.74 \text{ million } tCO_2e\end{aligned}$$

$$\begin{aligned}\text{Annual removals} &= (899.047 \text{ million cubic feet} / 51.05 \text{ cubic feet per dry ton})\\ &\quad \times 0.9072 \times (44 / 12)\\ &= 58.58 \text{ million } tCO_2e\end{aligned}$$

$$\text{Net Change in Forest Biomass} = (106.74 - 58.58) \text{ million } tCO_2e = 48.16 \text{ million } tCO_2e$$

This net change in forest biomass stocks is so far in excess of the about 0.5 million metric tCO_2e of wood from forests required by this plant (as calculated in a previous step) that we may assume this feedstock will be replaced by ongoing growth; thus, LAR for the wood feedstock equals 1.

For residues from mills:

LAR (i.e, AVOIDEMIT) = 1 if emissions would have occurred anyway; 0 if not

Because residues are a secondary forest-derived biomass from other wood processing mills, the assumption is that if not burned for energy at this plant, the feedstock would have been burned or decayed elsewhere, with or without energy productions, resulting in the same level of emissions.

Thus, burning it for energy is avoiding the same emissions elsewhere, and LAR for the residue feedstock equals 1.

- *Calculating Carbon in Products (PRODC)*

Carbon in Products (PRODC) is the carbon content in products, in CO_2e, made from processing of the biogenic feedstocks, including energy products like ethanol and lignin that are combusted (or used) elsewhere releasing their sequestered CO_2e to the atmosphere. This serves as a mass balance calculation which ensures that the sum of the carbon content in the products equals the carbon content in the feedstock. The mass of each product or co-product is multiplied by the carbon content and summed up and divided by the Potential Gross Emissions (PGE) to estimate the proportion of carbon that leaves the stationary combustion facility in the form of products.

Normally, analysis of the carbon content for various types of paper or other manufactured products would be combined with production quantities to estimate the CO_2e captured in the products. For this example, we simply assume the same relative proportions as reported by Côté et al. (2002). In that case, for a feedstock of 641 thousand tons, 231 thousand tons of paper were produced; hence carbon content in products is 0.36.

The formula for PRODC is:

$$\text{PRODC} = \text{CO}_2\text{e content of Products} / \text{PGE}$$

or

$$\text{PRODC} = [(\text{Product 1}) \times \text{English to Metric tons} \times (\text{Carbon content of product 1})] / \text{Potential Gross Emissions}$$

For wood from forests:

$$\text{PRODC} = [180{,}000 \text{ English tons} \times 0.9072 \text{ metric tons per English ton} \times 0.3 \text{ tons carbon per ton feedstock} \times 44/12\ \text{CO}_2 \text{ per C}] / 498{,}960\ \text{tCO}_2\text{e}$$

$$\text{PRODC} = 179{,}626\ \text{tCO}_2\text{e} / 498{,}960\ \text{tCO}_2\text{e} = 0.360$$

For residues from mills:

$$\text{PRODC} = [60{,}000 \text{ English tons} \times 0.9072 \text{ metric tons per English ton} \times 0.3 \text{ tons carbon per ton feedstock} \times 44/12\ \text{CO}_2 \text{ per C}] / 166{,}320\ \text{tCO}_2\text{e}$$

$$\text{PRODC} = 59{,}875\ \text{tCO}_2\text{e} / 166{,}320\ \text{tCO}_2\text{e} = 0.360$$

- *Step 1: Conclusion*

In the first step, the PGE from the feedstock are adjusted for feedstock losses (L), Level of Atmospheric Reduction (LAR), and any products that leave the facility (PRODC). The resulting term in overall equation is calculated as:

$$[\text{PGE} \times (1 + \text{L}) \times (1 - \text{LAR}) \times (1 - \text{PRODC})]$$

For wood from forests:

$$498{,}960\ \text{tCO}_2\text{e} \times (1 + 0.079) \times (1 - 1) \times (1 - 0.36) = 0\ \text{tCO}_2\text{e}$$

For residues from mills:

$$166{,}320\ \text{tCO}_2\text{e} \times (1 + 0.079) \times (1 - 1) \times (1 - 0.36) = 0\ \text{tCO}_2\text{e}$$

Step 2: Carbon storage resulting from incomplete utilization (SEQP)

Step 2 calculates the difference between what could be emitted by utilization of the feedstock (PGE) when combusted fully and what is actually emitted as a result of the production of a Sequestered Fraction in the form of post-combustion material. This term can include carbon sequestered in residuals like ash or carbon sequestered through carbon capture technology. Note that if these materials are sold for use outside the stationary source rather than disposed of, they should be counted in PRODC.

The Sequestered Fraction (SEQP) is the proportion of the feedstock carbon content that is contained in the derivative products that remain after biogenic feedstock combustion at the stationary source. In some production technologies, virtually all of the carbon in the feedstock is emitted as CO_2. In that event, Sequestered Fraction would be 0 or very close to 0. In other technologies, unburned carbon is left in the ash.

$$\text{SEQP} = \text{CO}_2\text{e sequestered from stationary source / PGE}$$

This case study assumes full combustion (of all feedstocks used for energy) and consequently no Sequestered Fraction, and thus,

For wood from forests:

$$[\text{PGE} \times \text{SEQP}] = 0\ \text{tCO}_2\text{e}$$

For residues from mills:

$$[\text{PGE} \times \text{SEQP}] = 0\ \text{tCO}_2\text{e}$$

Step 3: Carbon emissions/sequestration at the feedstock collection site (SITE_TNC)

In Step 3 we calculate the annualized difference in the stock of land-based carbon (above- and below-ground), other than feedstock growth, which results from implementation of biogenic feedstock production. This value may be zero, or it may be positive (indicating that additional emissions from land take place as a result of biogenic feedstock production) or negative (indicating that additional sequestration on land takes place as a result of biogenic feedstock production). As in

Step 1, this term is then adjusted to account for carbon in feedstock that is ultimately removed from the accounting framework in products that leave the facility.

For forestry case studies, since several products are removed from the same piece of land, specific sequestration effects of feedstock removal and land-use change need to be distributed among various feedstock uses. All of the effects cannot be assigned to just the bioenergy feedstock. For example, if 100 acres are harvested for roundwood and residues, and only the residues go to bioenergy with the roundwood going to saw mills, it would not be appropriate to have all of the emissions from land-use change attributed to the residues only. Some emissions need to be attributed to this harvested roundwood even if it is used for non-energy purposes. In this scenario, if SITE_TNC were to have a non-zero value, a proportion should be assigned to the pulp and paper mill.

However, SITE_TNC for this case study is zero since it is assumed that the harvest does not lead to changes in carbon stocks of non-feedstock carbon pools (like dead biomass).. This implies the annualized carbon stock of site sequestration is the same and site sequestration loss (or gain) is zero.

Step 4: Leakage (LEAK)

In Step 4 of the NBE formula, we incorporate the effects of leakage or indirect land-use change. LEAK is the leakage of biogenic carbon emissions generated outside the supply chain induced by market reactions to biogenic feedstock use for bioenergy (i.e., replacement of diverted crop, livestock or forest products due to a change in land use from conventional products to biomass feedstocks). The term is expressed as net emissions of tCO_2e that occur when producing the feedstock volume needed for stationary combustion. This value will only be calculated if a commercial market exists either for the feedstock being used or for the previous land use. LEAK may be estimated from previous published work, or it may be an assumed value, or it may come from another analysis.

In the current case study, all biomass purchases are for the production of pulp and paper, and the energy production therefore involves no effects on the biomass markets that could potentially lead to leakage. In other words, because no feedstock (roundwood or residues) was harvested solely for energy (it was harvested for paper or other forest products), the consumption of biomass for energy does not impact the market; essentially in a paper mill, all of the wood burned for energy is residual wood (or black liquor, also a byproduct). Hence, there is no demand for more roundwood or residues to be produced elsewhere and no market effect from this feedstock consumption, so there is no leakage.

$$\text{LEAK} = 0$$

Step 5: Net Biogenic Emissions (NBE)

Once all the various parts of the NBE equation are calculated in Steps 1 through 4, they are combined together to estimate the Net Biogenic Emissions (NBE). In this case study, the Net Biogenic Emissions associated with the conversion of wood to electricity at this facility are found by first calculating the potential emissions from the feedstock itself, adjusted for any feedstock material that is lost between the point of harvest and the point of combustion. This value is then adjusted to account for growth in the feedstock itself or avoided emissions from residue decomposition, and is further adjusted to account for the carbon embodied in Sequestered Fraction (SEQP) (e.g., ash) and

Carbon in Products (PRODC) (e.g., paper). Finally, terms that account for sequestration at the point of feedstock production and leakage are added.

$$\begin{aligned} \text{NBE} = {} & [\text{PGE} \times (1 + \text{L}) \times (1 - \text{LAR}) \times (1 - \text{PRODC})] \\ & - [\text{PGE} \times \text{SEQP}] \\ & + [\text{SITE\_TNC} \times (1 - \text{PRODC})] \\ & + [\text{LEAK} \times (1 - \text{PRODC})] \end{aligned}$$

For wood from forests:

$$\begin{aligned} \text{NBE} = {} & [(498{,}960) \times (1 + 0.0795) \times (1 - 1) \times (1 - 0.36)] - [498{,}960 \times 0] + [0 \times (1 - 0)] \\ & + 0 \times (1 - 0)\ \text{tCO}_2\text{e} \end{aligned}$$

$$\text{NBE} = 0\ \text{tCO}_2\text{e}$$

For residues from mills:

$$\text{NBE} = [(166{,}320) \times (1 + 0.078) \times (1 - 1) \times (1 - 0.36)] - [166{,}320 \times 0] + [0 \times (1 - 0)]$$

$$\text{NBE} = 0\ \text{tCO}_2\text{e}$$

Step 6: Biogenic Accounting Factor (BAF)

The last step in applying the accounting framework for this case study is to calculate the Biogenic Accounting (BAF). This number is the value that would be used by a facility to determine "net biogenic CO_2 emissions" from the source, given a particular feedstock and gross emissions value. It is typically between 0 and 1, though values >1 or <0 are possible in certain cases. The Biogenic Accounting Factor is calculated using the equation below (see Section 4):

$$\text{BAF} = \text{NBE} / \text{PGE}$$

For wood from forests:

$$\text{BAF} = 0\ \text{tCO}_2\text{e} / 498{,}960\ \text{tCO}_2\text{e} = 0$$

For residues from mills:

$$\text{BAF} = 0\ \text{tCO}_2\text{e} / 166{,}320\ \text{tCO}_2\text{e} = 0$$

The results for this case study are summarized in Table 1 below.

Table 1: Numeric results of the Net Biogenic Emissions equation variables

Variable	Value		Units
	Wood from Forests	Residues from mills	
Net Biogenic Emissions (NBE)	0	0	tCO_2e
Potential Gross Emissions (PGE)	498,960	166,320	tCO_2e
Level of Atmospheric Reduction (LAR)	1	1	Proportion (no units)
Carbon in Products (PRODC)	0.36	0.36	Proportion (no units)
Sequestered Fraction (SEQP)	0	0	Proportion (no units)
Net emissions gain on site (SITE_TNC)	0	0	tCO_2e
Leakage (LEAK)	0	0	tCO_2e
Proportion of Feedstock Lost (L)	0.079	0.079	Proportion (no units)
Biogenic Accounting Factor (BAF)	0	0	Proportion (no units)
Total Feedstock Produced (tons)	498,960	166,320	Dry tons per year
Land needed (ACRES)	N/A	N/A	Acres

Summary

This case study portrays a situation in which biomass energy production is not the primary function of the plant. Pulp and paper mills produce substantial quantities of heat and electric power through burning of residues from the pulping and papermaking process, generally using this energy in the internal functions of the mills. In such cases, biomass purchases are not primarily for energy production, so the leakage and emissions from indirect land-use change are not applicable. Mills, such as the one in this case, will often have relatively high proportions of PRODC and the NBE will depend largely on the LAR term representing avoided emissions and feedstock growth. In the State of Washington, forest growth far exceeds removals, and it is readily evident that biomass burned for energy will be replaced.

Additional Information

Additional information about this case-study scenario is provided below. Table 2 contains information about the biogenic emission system and Table 3 contains key data inputs and assumptions.

Table 2: Information about the case study parameters

System Variable	Description
Feedstock type	• Purchased roundwood and chips: 300,000 dry tons/year • Wood residues from other wood processing facilities: 100,000 dry tons/year
Feedstock source location	• Region: State and private forests in western Washington stateand residues from nearby sawmills.
Facility description	• Energy fate: heat and electricity co-generation • Example Facility size: 35 MW electricity generation • Example Facility location: Puget Sound region, Washington
Land-use change	• Prior and current land use: no land-use change; all biomass procurement operations are justified for manufacture of paper, not for energy production.
Feedstock loss	• Conveyance/Haulage: 0% of feedstock produced • Storage: 0% of feedstock produced • Processing/drying: 7.8% of feedstock (bark and residue decay, bleaching losses)
Sequestered Fraction/ Carbon in Products	• Products: 240,000 tons/yr paper
Feedstock characteristics	• Carbon content of feedstock(s): 200,000 metric tons carbon • Weight of feedstock used annually: 400,000 metric tons
Baseline	• Forest harvest: Growth exceeds removals in drain area by 82%, or approximately 48.17 million tons/yr. • Residues: would have decayed or burned without energy production.
Years for annualizing growth and sequestration changes	• Years of growth: Not applicable (no land-use change) • Years of sequestration and growth: Annualized estimates from forest inventory (Smith et al. 2009)
Leakage	• Market not affected/leakage not applicable

Table 3: Key inputs and relevant assumptions for case study analysis

Key Inputs	**Values**		**Units**	**Notes**
	Wood from Forests	***Residues from other mills***		
Feedstock needed	300,000	100,000	Bone dry tons	
Carbon content of feedstock	0.5	0.5	Carbon content/dry ton	
Carbon content of product	0.3	0.3	Carbon content in paper	Assumed based on Côté et al. (2002)
Product output	180,000	60,000	Tons paper	240,000 tons output allocated proportionally to sources
Transport and handling losses	0.0452	0.0452	Percentage of feedstock needed	Losses from decay of bark and chips
Process losses	0.0328	0.0328	Percentage of feedstock needed	Bleaching losses
Carbon in Product (e.g., paper)	54,000	18,000	Dry tons	

Key Inputs	**Notes**
Calculating PGE	Standard calculation where carbon is 50% of a dry ton of woody material
Calculating SEQP	Assumes about 36% of carbon in plant goes to paper, the rest is emitted.
Calculating SITE_TNC	No land-use change; set to zero
Calculating LEAK	No market effects from energy production; set to zero

References

The data used in this case study are based on the carbon balance illustrated in Côté et al. (2002), which is for a Kraft mill in Texas, scaled to reflect average mill conditions reported for the state of Washington in Smith and Hiserote (2010). Sources include:

Côté, W.A., R.J. Young, K.B. Risse, A.F. Costanza, J.P. Tonelli, and C. Lenocker (2002). "A carbon balance method for paper and wood products". *Environmental Pollution* 116: S1-S6.

Gustafson, R. and N. Raffaeli (2009). "Washington State pulp and paper mill boilers: current and potential renewable energy production". Department of Ecology Publication No. 09-07-048. State of Washington Department of Ecology. Available online at: http://www.ecy.wa.gov/pubs/0907048.pdf

Smith, W.B., P.D. Miles, C.H. Perry, and S.A. Pugh (2009). "Forest Resources of the United States, 2007." *Gen. Tech. Rep. WO-78*. Washington, DC: U.S. Dept. Agriculture, Forest Service, Washington Office. 336 p.

Smith, D. and B. Hiserote (2010). "Washington mill survey 2008." Washington State Department of Natural Resources, 110 p. Available online at: http://www.dnr.wa.gov/Publications/obe_econ_rprt_millsurv_2008.pdf

Young, R.J., C. Row, J.P. Tonelli, W.A. Côté, and C. Lenocker (2000). "Carbon sequestration and paper: a carbon balance assessment". Journal of Forestry 98(9):38-43.

Case Study 4: Calculating Net Biogenic Emissions from Converting Corn Stover to Electricity

Description

In this case study, we calculate net biogenic CO_2 emissions from an electricity generation facility in the Midwest that collects corn stover, which is taken into pyrolysis where the end products are electricity and biochar. This case study illustrates the soil carbon change from harvesting (a land-use management change) but not from direct land-use conversion. In this example, the plant has an output of 12.5 Megawatts per year, which requires 70,080 tons of corn stover per year.

This case study exhibits the importance of a number of variables for the accounting for net biogenic CO_2 emissions, including soil carbon change. This case study has a soil sequestration loss due to removal of the feedstocks. Additionally, this case study demonstrates different product outputs: electricity and biochar.

Overview

The overall formula for Net Biogenic Emissions is:

$$
\begin{aligned}
\text{NBE} = {} & [\text{PGE} \times (1 + \text{L}) \times (1 - \text{LAR}) \times (1 - \text{PRODC})] \\
& - [\text{PGE} \times \text{SEQP}] \\
& + [\text{SITE\_TNC} \times (1 - \text{PRODC})] \\
& + [\text{LEAK} \times (1 - \text{PRODC})]
\end{aligned}
$$

The following steps describe calculation of Net Biogenic Emissions (NBE) and the Biogenic Accounting Factor (BAF). Please refer to Section 5 of the accounting framework for detailed discussion of the equations. Steps 1 through 4 below work through the calculations required for the 4 square-bracketed terms in the equation above.

Step 1: Potential Gross Emissions (PGE), feedstock carbon lost along supply chain (L), Level of Atmospheric Reduction (LAR), and carbon leaving the accounting framework as products (PRODC)
Step 2: Carbon storage resulting from incomplete utilization (SEQP)
Step 3: Carbon Emissions/Sequestration at the Feedstock Production Site (SITE_TNC)
Step 4: Leakage (LEAK)
Step 5: Net Biogenic Emissions (NBE)
Step 6: Biogenic Accounting Factor (BAF)

Step 1: Potential Gross Emissions (PGE), feedstock carbon lost along supply chain (L), Level of Atmospheric Reduction (LAR), and carbon leaving the accounting framework as products (PRODC)

In Step 1, the difference between what could potentially be emitted if all of the feedstock produced is consumed (Potential Gross Emissions or PGE) and what is actually emitted as a result of the feedstock processing or combustion process is calculated. This begins with a calculation of the carbon that is contained in the feedstock as it leaves the production site. PGE is calculated with reference to the feedstock that is used by the facility, and then the proportion that is lost in transport is added, in order to find the actual quantity of feedstock that must be produced onsite to support a particular facility's feedstock utilization.

$$[\text{PGE} \times (1 + \text{L}) \times (1 - \text{LAR}) \times (1 - \text{PRODC})]$$

- ***Calculating Potential Gross Emissions (PGE)***

Potential Gross Emissions (PGE) are the metric tons of CO_2e contained in the feedstock as it enters the facility: in other words, this is the total CO_2e that could potentially be released. PGE is the product of the mass of feedstock needed by the facility and its carbon content. In this case study conversion factors are used to express the PGE as metric tons CO_2e. The calculation of PGE is a standard calculation, where carbon is a fixed percent of a dry ton. See Table 2 for case-study specific values for each of the coefficients.

$$\begin{aligned}\text{PGE} = {} & (\text{Feedstock needed}) \\ & \times (\text{Carbon content of feedstock}) \\ & \times \text{English to Metric tons} \\ & \times \text{Carbon to } CO_2e\end{aligned}$$

$$\text{PGE} = 70{,}080 \times 0.45 \times 0.9072 \times (44 / 12) = 104{,}901 \text{ t}CO_2e$$

- ***Calculating Proportion of Feedstock Lost (L)***

Feedstock Lost (L) is the additional proportion of feedstock production needed to overcome loss in conveyance, storage and plant handling. The case study assumes no plant losses, 10% losses during storage, and 0.5% loss during handling and transport. The following equations give the amount of potential emissions in the feedstock that must be produced (TFP) at the feedstock site.

$$\begin{aligned}\text{TFP} = {} & (\text{Feedstock needed}) \\ & \times (1 + \text{Plant Losses}) \\ & \times (1 + \text{Storage Losses}) \\ & \times (1 + \text{Losses during handling and transport})\end{aligned}$$

$$\text{TFP} = 70{,}080 \times (1 + 0) \times (1 + 0.10) \times (1 + 0.005) = 77{,}473 \text{ Tons per year}$$

and

$$\text{L} = (\text{TFP} / \text{Feedstock needed}) - 1$$

$$\text{L} = (77{,}473 \text{ Tons} / 70{,}080 \text{ Tons}) - 1 = 0.1055$$

- ***Calculating Level of Atmospheric Reduction (LAR)***

The Level of Atmospheric Reduction (LAR) is the proportional atmospheric CO_2e reduction that occurs either when: (a) feedstock growth sequesters atmospheric CO_2 during growth (GROW), or (b) emissions are avoided in the future from the decomposition of residues (AVOIDEMIT).

$$\text{LAR} = (\text{GROW} + \text{AVOIDEMIT}) / (\text{Feedstock needed} \times (1 + \text{L}))$$

LAR = AVOIDEMIT / TFP = 77,473 Tons per year/ 77,473 Tons per year = 1

In other words,

LAR = 1 if emissions would have occurred anyway; 0 if not

This is because corn stover is a residue material, the assumption is that it would have decayed in place if the electricity use had not occurred, resulting in the same level of emissions.[1] Thus avoided emissions are equivalent to TFP, and LAR equals 1.

- ***Calculating Carbon in Products (PRODC)***

Carbon in Products (PRODC) is the carbon content in products, in CO_2e, made from processing of the biogenic feedstocks, including energy products like ethanol and lignin that are combusted (or used) elsewhere releasing their sequestered CO_2e to the atmosphere, as well as non-energy products like DDGS that are used elsewhere. This accounting step covers the biogenic Carbon in Products moved offsite beyond the accounting scope, and serves as a mass balance calculation which ensures that the sum of the carbon content in the products equals the carbon content in the feedstock. The mass of each co-product is multiplied by the carbon content and summed up and divided by the Potential Gross Emissions (PGE) to estimate the proportion of carbon that leaves the stationary combustion facility in the form of products. In this case study, there is no PRODC as the product is electricity and does not embody carbon (biochar carbon is not sold in this case study and therefore described in the calculation of SEQP below). Therefore, PRODC = 0.

Step 1: Conclusion

As the final part of the first step, PGE from the feedstock is adjusted for feedstock losses (L) and Level of Atmospheric Reduction (LAR). This resulting formula is:

$$[\mathrm{PGE} \times (1 + \mathrm{L}) \times (1 - \mathrm{LAR}) \times (1 - \mathrm{PRODC})]$$

$$= 104{,}901\ \mathrm{tCO_2e} \times (1 + 0.1055) \times (1 - 1) \times (1 - 0) = 0\ \mathrm{tCO_2e}$$

Step 2: Carbon storage resulting from incomplete utilization (SEQP)

In Step 2, we calculate the difference between what potentially could be emitted by utilization of the feedstock (PGE) and what is actually emitted as a result of the production of a Sequestered Fraction (SEQP) in the form of post-combustion byproducts. This involves a calculation of the sum of carbon that is contained in the various byproducts of processing that leave the stationary source or are retained in post-combustion products such as ash and biochar.

Sequestered Fraction (SEQP) is the proportion of the feedstock carbon content that is contained in derivative products that remain after biogenic feedstock combustion at the stationary source. In some production technologies, virtually all of the carbon in the feedstock is emitted as CO_2. In that event, SEQP would be 0 or very close to 0. In other technologies, unburned carbon is left in the ash. For this case study, it is assumed that 14.8% of the feedstock goes to biochar and 95% of that is sequestered. Thus:

$$\mathrm{SEQP} = 0.148 \times 0.95 = 0.1406$$

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[1] For annual agricultural feedstocks such as corn kernels, the amount of carbon released at the stationary source is equivalent to the carbon taken up by the plant in the same year through photosynthesis. Thus if the feedstock is the corn plant rather than the stover, Feedstock Growth = TFP and LAR still equals 1.

PGE from the feedstock is then adjusted for the Sequestered Fraction calculated above. This part of the calculation becomes:

[PGE × SEQP]

$= 104{,}901\ tCO_2e \times 0.1406 = 14{,}749\ tCO_2e$

Step 3: Changes in carbon emissions/sequestration at the feedstock collection site (SITE_TNC)

Step 3 estimates the following term in the full NBE equation above:

[SITE_TNC × (1 − PRODC)]

SITE_TNC is the annualized change in the stock of land-based carbon (above- and below-ground), other than due to feedstock growth that results from implementation of biogenic feedstock production. SITE_TNC can be expressed in terms of Change in Net Site Emissions (SITEEMIT) and Change in Net Site Sequestration (SITESEQ) (Section 5.2.F of the accounting framework). As a result of these factors, SITE_TNC may be positive, indicating that additional emissions from land take place as a result of biogenic feedstock production, or negative, indicating that additional sequestration on land takes place as a result of biogenic feedstock production. As in Step 1, this term is adjusted to account for carbon in feedstock that is ultimately removed from the accounting framework in products that leave the facility (PRODC).

Alternatively, the changes can be partitioned into changes due to land-use change and management changes due to feedstock removal. This is the approach used here.

SITE_TNC may be calculated from a series of equations, as described below.

i. *Calculating Acres Needed (ACRES)*

The number of acres used for production of a given amount of feedstock (Total Feedstock Produced or TFP) is calculated in order to quantify the number of acres (ACRES) associated with biogenic feedstock production. This value is the land area over which the additional emissions or sequestration due to feedstock production in SITE_TNC will be calculated. This value is calculated as follows:

ACRES = TFP / Feedstock yield per acre

ACRES = 77,473 Tons / 1.5 Tons per acre = 51,649 acres

• *Calculating Sequestration and Emission Terms*

This case study assumes that stover is removed from existing acreage of corn production, and thus no changes in land use are assumed to occur as a result of feedstock production.

The initiation of stover harvest for energy production represents a change in the rate of carbon sequestration relative to what would happen in the absence of management change (feedstock removal). The primary result of feedstock removal in this example is a decline in the rate of carbon sequestration in soil. This decline is assumed to be 0.020 tons Carbon lost per ton of feedstock removed (derived as an average over runs with the Century model (see Metherell et al., 1993) performed at Colorado State University).[2] This decline is annualized linearly over 30 years, such that the new equilibrium soil carbon stock (with stover harvest) is lower than the previous equilibrium soil carbon stock (without stover harvest) and is reached 30 years after stover harvest is begun based on evidence in West and Post (2002) where all soil carbon disturbances of this nature reached equilibrium in 30 years. In the example presented here, this is quantified as:

Site Soil Sequestration Change = [TFP

× Carbon content of feedstock

× 0.9072

× (44 / 12)

× Carbon sequestration loss per ton feedstock carbon removed]

/ (Years to divide by)

Site Soil Sequestration Change= [77,473 Tons Feedstock Removed per year × 0.45 × 0.907 × (44 / 12) × 0.020 Tons Carbon lost per Ton of Feedstock Removed]/ 30 years

Site Soil Sequestration Change (loss) = 77.312 tCO_2e per year

This annual rate of change in soil carbon levels can be expressed per unit acre (SITE_TNCacre) using the ACRES term calculated above:

STE_TNCacre = 77.312 tCO_2e per year/ 51,649 acres = 0.0015 tCO_2e per acres per year

Step 3: Conclusion

The equations above are combined to calculate SITE_TNC as follows:

SITE_TNC = Site Sequestration Lost due to Feedstock Removal

+ Site Sequestration Lost due to Land-Use Change

+ Site Emissions Gain

SITE_TNC = 77.312 tCO_2e + 0 + 0 = 77.312 tCO_2e increase in emissions

Step 4: Leakage (LEAK)

Leakage is assumed to be zero for this case study. LEAK = 0

Step 5: Net Biogenic Emissions (NBE)

In this case study, the Net Biogenic Emissions (NBE) associated with the conversion of corn stover to electricity at this facility are found by first calculating the potential emissions from the feedstock itself, adjusted for any feedstock material that is lost between the point of harvest and the point of

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[2] Colorado State University (2010). Century Model runs performed by Steve Ogle, Colorado State University to calculate site carbon sequestration loss per ton of feedstock removed. December, 2010.

combustion. This value is then adjusted to account for growth in the feedstock itself or avoided emissions from residue decomposition, and is further adjusted to account for the carbon embodied in Sequestered Fraction (SEQP) (e.g., ash) and Carbon in Products (PRODC) (e.g., paper). Finally, terms that account for sequestration at the point of feedstock production and leakage are added.

$$\begin{aligned} NBE = {} & [PGE \times (1 + L) \times (1 - LAR) \times (1 - PRODC)] \\ & - [PGE \times SEQP] \\ & + [SITE\_TNC \times (1 - PRODC)] \\ & + [LEAK \times (1 - PRODC)] \end{aligned}$$

$$\begin{aligned} NBE = {} & [104{,}901\ tCO2e \times (1 + 0.106) \times (1 - 1) \times (1 - 0)] - [104{,}901\ tCO2e \times 0.1406] \\ & + [77.312\ tCO2e \times (1 - 0)] + [0 \times (1 - 0)] \end{aligned}$$

$$NBE = 0 - 14{,}749.13\ tCO2e + 77.312\ tCO2e + 0\ tCO_2e$$

$$NBE = -14{,}671.82\ tCO_2e$$

Step 6: Biogenic Accounting Factor (BAF)

The Biogenic Accounting Factor (BAF) is the ratio between the NBE and the PGE and should be between −1 and 1. It is calculated as follows:

$$BAF = NBE / PGE$$

$$BAF = -14{,}671.82\ tCO_2e / 104{,}901\ tCO_2e$$

$$BAF = -0.140$$

Thus, the use of the feedstock in this example results in a net decrease in atmospheric CO_2e, primarily due to the production and sequestration of carbon in biochar.

The results for this case study are summarized in Table 1 below.

Table 1: Numeric results of the Net Biogenic Emissions equation variables

Variable	Value	Units
Net Biogenic Emissions (NBE)	−14,671.82	Tons CO_2e
Potential Gross Emissions (PGE)	104,901.35	Tons CO_2e
Level of Atmospheric Reduction (LAR)	1.000	Proportion (no units)
Carbon in Products (PRODC)	N/A	Tons CO_2e
Sequestered Fraction (SEQP)	0.1406	Proportion (no units)
Net emissions gain on site (SITE_TNC)	77.312	Tons CO_2e
Leakage (LEAK)	N/A	Tons CO_2e
Proportion of Feedstock Lost (L)	0.1055	Proportion (no units)
Biogenic Accounting Factor (BAF)	−0.140	Proportion (no units)
Total Feedstock produced (TFP)	77,473.44	Tons
Land needed (ACRES)	51,649	Acres

Summary

The Net Biogenic Emissions for this case study are −14,671.82 tons/yr (i.e., atmospheric carbon is reduced through the feedstock use), largely through sequestration of carbon in biochar. The fraction of the original carbon in the corn stover that is sequestered in biochar is equal to 14.8%. This is offset slightly by a small increment to net biogenic emissions through a decline in carbon sequestration on site of 77.312tons CO_2e per year over a 30 year period due to the soil carbon that is lost in the removal of the corn stover.

Additional Information

Additional information about this case-study scenario is provided below. Table 2 contains information about the biogenic emission system and Table 3 contains key data inputs and assumptions.

Table 2: Information about the case study parameters

System Variable	Description
Feedstock type	• Corn Stover (100 %) • Total feedstock: 70,080 tons/year
Feedstock source location	• State/Region: Midwest • Neighboring States: N/A • Imports/Exports: N/A
Facility description	• Energy fate: Fast pyrolysis with oil and gas used in generating electricity • Example facility size: 12.5 MW • Example facility location: Unspecified
Land-use change	• Prior and current land use: No land-use conversion • Sequestration: Loss of soil carbon when stover is removed • Management scenario: Unspecified
Feedstock loss	• Conveyance/Haulage: 0.5% of feedstock produced • Storage: 10% of feedstock produced • Pre-processing/drying: 0% of feedstock produced
Unburned fraction/products	• Unburned fraction: 15% of feedstock (biochar) • Products: Biochar (95% of biochar is sequestered)
Feedstock characteristics	• Carbon content: 0.45 carbon content per ton (corn stover) • Mass of feedstock: 70,080 dry tons/year (corn stover)
Baseline	• Current lands use: No land-use conversion • Effects of alternative land use: N/A
Years for annualizing growth and sequestration changes	• Years of growth: 30 years
Leakage	• None computed

Table 3: Key inputs and relevant assumptions for case study analysis

Key Inputs	**Values**	**Units**	**Notes**
	Midwest		
Feedstock needed	70,080	Tons of corn stover	
Carbon Content of feedstock	0.45	Carbon content/ton	Amount of carbon in a ton of feedstock
Carbon content of biochar	1.0	Carbon content in biochar	This is tons carbon in a ton of biochar
Biooil yield	0.598	Amount of carbon in feedstock going into biooil	
Biochar yield	0.148	Amount of carbon in feedstock going into biochar	
Biogas yield	0.142	Amount of carbon in feedstock going into biogas	
Electricity output pyrolysis	12.5	Megawatts	Electrical output
Storage Losses	0.100	Percentage of feedstock needed	Assumed loss in storing switch grass to time of consumption. Less in south due to longer harvest season
Handling and transport losses	0.005	Percentage of feedstock needed	Assumed loss in moving corn stover to point of consumption and 0 losses in plant
Yield per acre	1.500	Yield of corn stover per acre of land in	
Soil Carbon sequestration lost per ton removed	0.020	Ton of carbon per ton of feedstock	Average of Century model runs at Colorado State University
Sequestration loss of biochar	0.050	Tons of biochar retained in sequestration per ton created at the stationary source	Assumed proportional loss of CO_2e content in biochar due to handling/conveyance loss, fire, and disappearance from field
Years for annualizing growth and sequestration	30	Years	The growth is divided by 30 and that amount is applied against annualized emissions.

Key Inputs	**Notes**
Calculating PGE	Standard calculation where carbon is a fixed percent of a dry ton
Calculating SEQP	Assumes 15% of carbon in plant goes to biochar, rest is emitted and 95% of that is sequestered. This goes into Sequestered Fraction.
Calculating SITE_TNC	Sequestration soil loss from residue recovery but gain from biochar production
Calculating LEAK	None computed

References

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Case Study 5: Calculating Net Biogenic Emissions from Converting Short Rotation Woody Energy Crop (Poplar) to Electricity

Description

In this case study, we calculate net biogenic CO_2 emissions from an electricity generation facility in the Midwest that collects and converts poplar to electricity, with ash as a byproduct. The results are shown in Table 1. This case study illustrates the soil and standing carbon change from direct land-use change. In this example, the plant has an output of 100 Megawatts per year, which requires 800,364 tons of poplar per year. See Table 2 for additional information about the biogenic emission system addressed in this case study.

This case study exhibits the importance of a number of variables on the accounting for net biogenic CO_2 emissions including a direct land-use change from conventional tilled crops to poplar. Additionally, this case study demonstrates a situation where there is standing carbon in new feedstock.

These following sections walk through this formula in five steps:

Step 1: Potential Gross Emissions (PGE), feedstock carbon lost along supply chain (L), Level of Atmospheric Reduction (LAR), and carbon leaving the accounting framework as products (PRODC)
Step 2: Carbon storage resulting from incomplete utilization (SEQP)
Step 3: Carbon Emissions/Sequestration at the Feedstock Production Site (SITE_TNC)
Step 4: Leakage (LEAK)
Step 5: Net Biogenic Emissions (NBE)
Step 6: Biogenic Accounting Factor (BAF)

Overview

As presented previously, the full accounting framework formula for Net Biogenic Emissions is:

$$\begin{aligned}
\text{NBE} = & [\text{PGE} \times (1 + \text{L}) \times (1 - \text{LAR}) \times (1 - \text{PRODC})] \\
& - [\text{PGE} \times \text{SEQP}] \\
& + [\text{SITE\_TNC} \times (1 - \text{PRODC})] \\
& + [\text{LEAK} \times (1 - \text{PRODC})]
\end{aligned}$$

In each of the Steps 1 through 4, we step through the calculations required for the square-bracketed terms.

Step 1: Potential Gross Emissions (PGE), feedstock carbon lost along supply chain (L), Level of Atmospheric Reduction (LAR), and carbon leaving the accounting framework as products (PRODC)

In Step 1, the difference between what could potentially be emitted if all of the feedstock produced is consumed, and what is actually emitted as a result of the feedstock processing or combustion process is calculated. It is then adjusted for the amount of carbon contained in products that ultimately leave the source and thus occur outside the accounting framework. This Step corresponds to the following term, which appears first in the full NBE equation above:

$$[\text{PGE} \times (1 + \text{L}) \times (1 - \text{LAR}) \times (1 - \text{PRODC})]$$

The calculation begins with the carbon that is contained in the feedstock as it leaves the production site (e.g., farm, forest). Note that PGE is calculated with reference to the feedstock that is used by the facility. The proportion that is lost in transport (L) is added, in order to find the actual quantity of feedstock that must be produced at the production site to provide feedstock for the facility.

- ***Calculating Potential Gross Emissions (PGE)***

Potential Gross Emissions (PGE) is the metric tons of CO_2e that could potentially be released out the stationary source stack. In this case study, PGE is the product of the mass of feedstock needed by the facility and its carbon content. In this case study conversion factors are used to express the final PGE as metric tons CO_2e. The calculation of PGE is a standard calculation where carbon is a fixed percent of a dry ton. See Table 4 and 5 for case-study specific values for each of the coefficients.

$$\begin{aligned}\text{PGE} = {} & (\text{Feedstock needed}) \\ & \times (\text{Carbon content of feedstock}) \\ & \times \text{English to Metric tons} \\ & \times \text{Carbon to } CO_2e\end{aligned}$$

$$\text{PGE} = 800{,}364 \text{ Tons of feedstock needed} \times 0.5 \times 0.9072 \times (44 / 12) = 1{,}331{,}165 \text{ t}CO_2e$$

- ***Calculating Proportion of Feedstock Lost (L)***

Feedstock Lost (L) is the proportion of additional feedstock production to overcome loss in conveyance, storage and plant handling. The case study assumes zero plant losses, 4% losses during storage, and 0.5% losses during handling and transport. The following equations give the amount of potential emissions in the feedstock that must be produced (Tons of Feedstock Produced or TFP) at the feedstock site.

$$\begin{aligned}\text{TFP} = {} & (\text{Feedstock needed}) \\ & \times (1 + \text{Plant Losses}) \\ & \times (1 + \text{Storage Losses}) \\ & \times (1 + \text{Losses during handling and transport})\end{aligned}$$

$$\text{TFP} = (800{,}364 \text{ Tons of feedstock needed}) \times (1 + 0) \times (1 + 0.04) \times (1 + 0.005) = 836{,}540 \text{ tons of feedstock produced}$$

and

$$\text{L} = (\text{TFP} / \text{Feedstock needed}) - 1$$

$$\text{L} = (836{,}540 \text{ Tons} / 800{,}364 \text{ Tons}) - 1 = 0.0452$$

- ***Calculating Level of Atmospheric Reduction (LAR)***

The Level of Atmospheric Reduction (LAR) is the proportional atmospheric CO_2e reduction that occurs either when: (a) feedstock growth sequesters atmospheric CO_2 (GROW), or (b) emissions are avoided in the future from the decomposition of residues (AVOIDEMIT).

Note that avoided emissions are not relevant for this case study as there are no residue based feedstocks. In the case study presented here, once the facility is established there would be a constant fraction of the feedstock source area in each stage of the poplar lifecycle, and the total carbon stored in poplar biomass in the plantations as a whole would be constant. This means annual cutting loss is matched by annual growth, carbon sequestration loss would be zero, and LAR = 1. In equation terms,

$$\text{LAR} = (\text{GROW} + \text{AVOIDEMIT}) \ / \ (\text{Feedstock needed} \times (1 + \text{L}))$$

$$\text{LAR} = \text{GROW} \ / \ \text{TFP} = 836{,}540 \text{ Tons per year} / \ 836{,}540 \text{ Tons per year} = 1.$$

- ***Calculating Carbon in Products (PRODC)***

Carbon in Products (PRODC) is the carbon content in products, in CO_2e, made from processing of the biogenic feedstocks, including energy products like ethanol and lignin that are combusted (or used) elsewhere releasing their sequestered CO_2e to the atmosphere, as well as non-energy products like DDGS that are used elsewhere. This accounting step covers the biogenic Carbon in Products moved elsewhere. This serves as a mass balance calculation which ensures that the sum of the carbon content in the products equals the carbon content in the feedstock. The mass of each co-product is multiplied by the carbon content and summed up and divided by the Potential Gross Emissions (PGE) to estimate the proportion of carbon that leaves the stationary combustion facility in the form of products.

In this case study, there is no PRODC as the product is electricity and does not embody carbon.

- ***Step 1: Conclusion***

In the first step, the PGE from the feedstock are adjusted for feedstock losses (L) and Level of Atmospheric Reduction (LAR).

$$[\text{PGE} \times (1 + \text{L}) \times (1 - \text{LAR})]$$

$$= 1{,}331{,}165 \ tCO_2e \times (1 + 0.0452) \times (1 - 1) = 0 \ tCO_2e$$

Step 2: Carbon storage resulting from incomplete utilization (SEQP)

In Step 2, we calculate the difference between what potentially could be emitted by utilization of the feedstock (PGE) and what is actually emitted as a result of the production of Sequestered Fraction (SEQP) in the form of byproducts. This involves a calculation of the sum of carbon that is contained in the various byproducts of processing that leave the stationary source or is retained in post-combustion products such as ash.

i. ***Calculating Sequestered Fraction (SEQP)***

Sequestered Fraction (SEQP) is the proportion of the feedstock carbon content that is contained in the derivative products that remain after biogenic feedstock combustion at the stationary source. In some production technologies, virtually all of the carbon in the feedstock is emitted as CO_2. In that event, SEQP would be 0 or very close to 0. In other technologies, unburned carbon is left in the ash.

In this case study, it is assumed that 1 percent of carbon in plant biomass remains as ash and the rest is emitted. This 1% goes into SEQP.

SEQP = 0.01

$[\text{PGE} \times \text{SEQP}] = 1{,}331{,}165\ \text{tCO}_2\text{e} \times 0.01 = 13{,}312\ \text{tCO}_2\text{e}$

Step 3: Carbon emitted from the site where feedstock was grown/collected (SITE_TNC)

In Step 3 we calculate SITE_TNC, which is the annualized difference in the stock of land-based carbon (above and below ground) that results from changing to biogenic feedstock production from some other land use or production system. There will often be no difference, or this change can be positive or negative and occur over a period of years. This term is calculated from the three equations below.

i. Calculating Acres Needed (ACRES)

The acres required for total feedstock production (TFP) are needed to account for the appropriate net emissions from site. This can be calculated as follows, assuming a yield per acre from the poplar plantations of 4.639 tons/acre[3] based on data used in FASOMGHG (Beach et al., 2010):

ACRES = TFP / Yield per acre

ACRES = 836,540.453 Tons of Feedstock Produced/ 4.639 Tons per Acre = 180,328 acres

- *Calculating Sequestration and Emission Terms*

Total Net Change in Site Emissions (SITE_TNC) can be expressed in terms of Change in Net Site Emissions (SITEEMIT) and Change in Net Site Sequestration (SITESEQ), as reflected in the accounting framework (section 5.2.F, Equation 9):

SITE_TNC = (SITEEMIT) − (SITESEQ)

Where Change in Net Site Emissions (SITEEMIT) is the net addition to CO_2e emissions due to the feedstock production/removal (this term is negative if emissions are reduced) and Change in Net Site Sequestration (SITESEQ) is the net addition to sequestration due to the feedstock production/removal.

Another representation of this equation allows for identification of changes in net site emissions that come from land-use conversion (including changes in soil and standing carbon due to direct land-use change) and management changes (such as removing residues that were previously left to decay for bioenergy use). This representation, which is used in this case study for illustration, can be shown as:

SITE_TNC = [(Site Sequestration change due to management change)

+ (Site Sequestration change due to land-use conversion)]

+ Site Emissions Gain [from land-use and management changes]

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[3] Note yield value may vary between regions. For example, the value for the yield per acre for the Southeast is 4.038 tons per acre. This implies that the number of acres needed to calculate Net Emissions from Site will be greater.

In this case study, site sequestration change due to management change (feedstock removal for bioenergy) is assumed to be zero as management for poplar production does not alter site carbon pools other than through effects captured below). Thus the first term = 0.

There is a land-use conversion in this example from cropland to poplar so there is an annualized stock change in land-based carbon (above and below ground) due to direct land-use change. In this case there are two carbon stocks to consider: the soil and the aboveground biomass carbon.

The soil carbon under conventional tilled crops is assumed to be 62.86 tCO_2e. When poplar is planted it is assumed to raise soil carbon to 74.53 tCO_2e using data from the FORCARB model (Smith and Heath, pers. comm.) as used in FASOMGHG (Beach et al., 2010). The standing stock of aboveground poplar biomass is 23.15 tCO_2e (computed below). This transition to steady-state soil and vegetation carbon stocks under poplar is assumed to occur linearly over 30 years.

The standing stock of carbon in aboveground biomass in the poplar system is calculated using the following formula (assuming a seven-year rotation, represented as "1/7+2/7+3/7+4/7+5/7+6/7").

$$\begin{aligned}\text{Standing stock of carbon in feedstock} = {} & \text{Yield (tons per acre)} \\ & \times (1/7+2/7+3/7+4/7+5/7+6/7) \\ & \times \text{Carbon content of feedstock} \\ & \times \text{English to Metric tons} \\ & \times \text{Carbon to } CO_2e\end{aligned}$$

$$\begin{aligned}\text{Standing stock} = {} & 4.639 \text{ Tons per acre} \times (1/7+2/7+3/7+4/7+5/7+6/7) \times 0.5 \\ & \times 0.9072 \times (44/12)\end{aligned}$$

$$\text{Standing stock of carbon} = 23.15\ tCO_2e \text{ per acre}$$

On a per acre basis, the net change in sequestration/emissions (SITE_TNCacre) therefore is:

$$\begin{aligned}\text{SITE\_TNCacre} &= (\text{Soil plus Standing Carbon Before} - \text{Soil plus Standing Carbon After}) \\ &= 62.86\ tCO_2e - (74.53\ tCO_2e + 23.15\ tCO_2e) = -34.82\ tCO_2e \text{ per acre}\end{aligned}$$

We then multiply the per acre Change in Net Site Emissions (SITE_TNCacre) with the number of acres. Also, this transition to the acreage in poplar needed to supply the facility is assumed to occur linearly over 30 years. Thus, the annualized change for the net site emissions for the total acreage is calculated as follows:

$$\begin{aligned}\text{Site Sequestration Change} = {} & \text{ACRES} \\ & \times (\text{SITE\_TNCacre}) \\ & / (\text{Time period over which to annualize the change})\end{aligned}$$

$$\text{SITE\_TNC} = (180{,}327.75 \text{ acres} \times -34.82 \text{ tCO}_2\text{e per acre}) / 30$$

$$= -209{,}280.90 \text{ tCO}_2\text{e}$$

Since the SITE_TNC term is in units of emissions (or lost sequestration), a negative value indicates a net sequestration gain.

- ***Concluding Changes in Site Net Emissions (SITE_TNC)***

SITE_TNC is calculated here, for illustration, as:

$$\text{SITE\_TNC} = [\text{Site Sequestration lost due to feedstock removal}$$

$$+ \text{Site Sequestration lost due to Land-Use Change}]$$

$$+ \text{Site Emissions Gain}$$

$$\text{SITE\_TNC} = 0 + (-209{,}280.90 \text{ tCO}_2\text{e}) + 0 = -209{,}280.90 \text{ tCO}_2\text{e}$$

Thus, in this case study, there is a net gain in site carbon sequestration (and a negative change in site emissions).

Step 4: Leakage (LEAK)

In Step 4 of the NBE formula, we calculate leakage or indirect land-use change. LEAK is the leakage of biogenic carbon emissions generated outside the supply chain induced by market reactions to biogenic feedstock use for bioenergy (i.e., replacement of diverted crop, livestock or forest products due to a change in land use from conventional products to biomass feedstocks). The term is expressed as net emissions of metric tons CO_2e that occur when producing the feedstock volume needed for stationary combustion.[4] For this case study, since calculating appropriate leakage values is outside the scope of this report, we set LEAK = 0.

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[4] As explained in Section 3 of the report, leakage is the unanticipated decrease or increase in GHG benefits (i.e., emissions) outside of a project's accounting boundary as a result of project activities. In these case studies, leakage refers to the biogenic CO_2 emissions generated outside the supply chain induced by market reactions to biogenic feedstock use for bioenergy (e.g. emissions caused by land use changes that result from replacement of the diverted crop or forest product). Where it is appropriate to include a value for emissions from leakage, such an estimate should be included when possible. Development of a methodology for calculating leakage, or assessing potential values from existing work for use in this framework, however, is beyond the scope of this report. At the same time, we note that leakage can be substantial. For this case study, as an example, leakage calculations per acre might be drawn from the PhD dissertation by Kim. In that dissertation, a range of leakage rates are computed depending on the amount of land use change. The study also considered methane savings due to changes in rice acreage. The leakage estimates are about 20%, and half of that was due to methane, so here could use 10% for changes from cropland. To convert this into a carbon quantity we might use the average poplar yield of 4.64 tons per acre in the Midwest plus a conversion to carbon then CO_2, so—per acre of switchgrass converted from crop land—we would get the following leakage amounts:

$$\text{Leakage rate per acre} = 4.64 \times 0.10 \times 0.9072 \times (44 / 12) = 1.5434 \text{ tCO}_2\text{e/ acre}$$

and

$$\text{Leak} = 1.5434 \text{ tCO2e/ acre} \times 180{,}327.75 \text{ acres} = 278{,}326.800 \text{ t CO}_2\text{e}$$

Since there is no carbon leaving in products, no adjustment for PRODC would be required, and:

Step 5: Net Biogenic Emissions (NBE)

In this case study, the Net Biogenic Emissions associated with the conversion of wood to electricity at this facility are found by first calculating the difference between the emissions from the feedstock itself, adjusted for any feedstock material that is lost between the point of harvest and the point of combustion. This value is further adjusted to account for the carbon embodied in Sequestered Fraction (SEQP) (e.g., ash) and Carbon in Products (PRODC) (e.g., paper). Finally, terms that account for sequestration at the point of feedstock production and leakage are added.

$$\begin{aligned} \text{NBE} = {} & [\text{PGE} \times (1 + \text{L}) \times (1 - \text{LAR}) \times (1 - \text{PRODC})] \\ & - [\text{PGE} \times \text{SEQP}] \\ & + [\text{SITE\_TNC} \times (1 - \text{PRODC})] \\ & + [\text{LEAK} \times (1 - \text{PRODC})] \end{aligned}$$

For this case study and for feedstock sourced from the Midwest:

$$\begin{aligned} \text{NBE} = {} & [1{,}331{,}165\ \text{tCO}_2\text{e} \times (1 + 0.0452) \times (1 - 1)) \times (1 - 0)] - [1{,}331{,}165\ \text{tCO}_2\text{e} \times 0.010] \\ & + [-209{,}280.90\ \text{tCO}_2\text{e} \times (1 - 0)] + [0 \times (1 - 0)] \end{aligned}$$

$$\text{NBE} = -222{,}593\ \text{tCO}_2\text{e}$$

Step 6: Biogenic Accounting Factor (BAF)

The BAF is calculated as follows:

$$\text{BAF} = \text{NBE} / \text{PGE}$$

For this case study and for feedstock sourced from the Midwest:

$$\text{BAF} = -222{,}593\ \text{tCO}_2\text{e} / 1{,}331{,}165\ \text{tCO}_2\text{e}$$

$$\text{BAF} = -0.167$$

The results for this case study are summarized in Table 1 below.

$$[\text{LEAK} \times (1 - \text{PRODC})] = 278{,}326.800 \times (1 - 0) = 278{,}326.800\ \text{tCO}_2\text{e}$$

The NBE and BAF calculated including this leakage value would be -55,734 tCO_2e and 0.0.042 respectively, rather than -222,593, tCO_2e and -0.167.

Table 1: Numeric results of the Net Biogenic Emissions equation variables

Variable	Value		Units
	Midwest	Southeast	
Net Biogenic Emissions (NBE)	−222,593	253,741	tCO_2e
Potential Gross Emissions (PGE)	1,331,165	1,331,165	tCO_2e
Level of Atmospheric Reduction (LAR)	1.000	1.000	Proportion (no units)
Carbon in Products (PRODC)	0.000	0.000	tCO_2e
Sequestered Fraction (SEQP)	0.010	0.010	Proportion (no units)
Net emissions gain on site (SITE_TNC)	−209,280	−240,429	tCO_2e
Leakage (LEAK)	0	0	tCO_2e
Proportion of Feedstock Lost (L)	0.0452	0.0452	Proportion (no units)
Biogenic Accounting Factor (BAF)	−0.167	−0.191	Proportion (no units)
Total Feedstock produced (TFP)	836,540	836,540	Tons
Land needed (ACRES)	180,328	207,167	Acres

Conclusions

This case study demonstrates a site sequestration gain due to the direct land-use change from conventional tilled crop to poplar. There is a gain in the soil and standing carbon when poplar is planted to replace crops. As a result, there is a net gain of 210,198 ton CO_2e (with a BAF of −0.167) in biogenic emissions in this region (Midwest).

Additional Information

Additional information about this case-study scenario is provided below. Table 2 contains information about the biogenic emission system and Table 3 contains key data inputs and assumptions. Finally, references for this case study are provided.

Table 2: Information about the case study parameters

System Variable	Description
Feedstock type	• Poplar (100 %) • Total feedstock: 800,364 tons per year
Feedstock source location	• State/Region: Midwest • Neighboring States: N/A • Imports/Exports: N/A
Facility description	• Energy fate: Fast pyrolysis with oil and gas used in generating electricity • Example facility size: 100 MW • Example facility location: Unspecified
Land-use change	• Prior and current land use: Conventional tilled crops • Sequestration: Gain in soil and standing carbon when poplar replaces crops • Management scenario: Unspecified
Feedstock loss	• Conveyance/Haulage: 0.5% of feedstock produced • Storage: 4% of feedstock produced • Pre-processing/drying: 0% of feedstock produced
Sequestered Fraction	• Sequestered Fraction: 1% of feedstock is converted to ash • Products: N/A
Feedstock characteristics	• Carbon content: 0.5 carbon content per ton (poplar) • Mass of feedstock: 800,364 tons per year (poplar)
Baseline	• Current lands use: Conventional tilled crop • Effects of alternative land use: Yes
Leakage	• Emissions: 93 kg of CO_2e internationally per ton of switchgrass • Sequestration: 15 kg per ton of switchgrass.

Table 3: Key inputs and relevant assumptions for case study analysis

Key Inputs	**Values**		**Units**	**Notes**
	Midwest	**Southeast**		
Feedstock needed	800,364	800,364	Tons of dry poplar	
Carbon Content of feedstock	0.50	0.50	Carbon content/ton	Amount of carbon in a ton of feedstock
Electricity output pyrolysis	100	100	Megawatts	Electrical output
Storage Losses	0.040	0.040	Percentage of feedstock needed	Assumed loss in storing switch grass to time of consumption. Less in south due to longer harvest season
Handling and transport losses	0.005	0.005	Percentage of feedstock needed	Assumed loss in moving switchgrass to point of consumption and 0 losses in plant
Yield per acre	4.639	4.038	dry tons per acre of land	FASOMGHG (Beach et al., 2010)
Sequestered Fraction	0.010	0.010	Proportion of carbon in feedstock that is sequestered	Ash
Years for annualizing growth and sequestration	30	30	Years	

Key Inputs	Notes
Calculating PGE	Standard calculation where carbon is a fixed percent of a dry ton
Calculating SEQP	Assumes 1% of carbon in plant goes to ash. This goes into Sequestered Fraction.
Calculating SITE_TNC	Sequestration soil gain from replacing crop with poplar . Sequestration gain from standing poplar. carbon also sequestered in ash.
Calculating LEAK	Computed on a per acre basis

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