Framework for Assessing Biogenic CO_2 Emissions from Stationary Sources

United States Environmental Protection Agency, Office of Air and Radiation

Office of Atmospheric Programs, Climate Change Division

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Executive Summary

FRAMEWORK FOR ASSESSING BIOGENIC CO_2 EMISSIONS FROM STATIONARY SOURCES

This report presents a methodological framework for assessing the extent to which the production, processing, and use of biogenic material at stationary sources results in a net atmospheric contribution of biogenic carbon dioxide (CO_2) emissions. Biogenic CO_2 emissions are defined as CO_2 emissions related to the natural carbon cycle,[1] as well as those resulting from the production, harvest, combustion, digestion, fermentation, decomposition, and processing of biologically based materials.[2]

The framework examines direct emissions of biogenic CO_2 from stationary sources that combust or process biogenic material, taking into account factors related to the biological carbon cycle. These factors include changes in biogenic carbon-based stocks and emissions—known as "carbon fluxes"[3]—that occur (or are avoided) as a result of (1) feedstock growth and harvest; (2) processing, transport, storage, and use of a biogenic feedstock at the stationary source; and/or (3) the possible alternative fate of biogenic feedstock materials if not used for bioenergy.[4] The framework is a revision of the U.S. Environmental Protection Agency's (EPA's) original September 2011 *Draft Accounting Framework for Biogenic CO_2 Emissions from Stationary Sources* and was developed in response to a peer review by the Biogenic Carbon Emissions Panel of EPA's Science Advisory Board (SAB Panel). In the review,[5] the SAB Panel stated that:

> Carbon neutrality cannot be assumed for all biomass energy a priori. There are circumstances in which biomass is grown, harvested and combusted in a carbon neutral fashion but carbon neutrality is not an appropriate a priori assumption; it is a conclusion that should be reached only after considering a particular feedstock's

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[1] The term "carbon cycle" is used to describe the flow of carbon (in various forms, for example, as CO_2) through the atmosphere, ocean, terrestrial biosphere, and lithosphere (IPCC, 2007a).
[2] Biologically based feedstocks, also referred to in this report as "biogenic materials," are non-fossilized and biodegradable organic materials originating from modern or contemporarily grown plants, animals, or microorganisms (including products, by-products, 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). These feedstocks do not include materials such as peat, coal, petroleum, natural gas, and other products that are derived from biologic materials but are considered non-renewable during the time frame relevant to policymaking.
[3] The IPCC defines "carbon flux" as the transfer of carbon from one carbon pool to another in units of measurement of mass per unit area and time (IPCC, 2000). The term "flux" is used here to encompass biogenic CO_2 and methane emissions to the atmosphere, and removal of carbon (C) from the atmosphere. Removal of C from the atmosphere is also referred to as "carbon sequestration" (EPA, 2014).
[4] The framework includes consideration of carbon cycle fluxes associated with or avoided by the conversion of biogenic materials at stationary sources. For completeness, biogenic carbon and carbon-based gases—carbon dioxide and methane—are included within the framework as applied to forest-, agriculture-, and waste sector-derived feedstocks. Throughout the report, the term "biogenic CO_2" is often used to represent these carbon-based stocks and gases.
[5] The final peer review report from the SAB Biogenic Carbon Emissions Panel on the draft framework was published on September 28, 2012 (Swackhamer and Khanna, 2011).

> production and consumption cycle. There is considerable heterogeneity in feedstock types, sources and production methods and thus net biogenic carbon emissions will vary considerably.

Consistent with this statement, the revised framework provides a description of the types of factors to consider when assessing biogenic CO_2 emissions and presents an equation that could be used to calculate the extent to which use of biogenic materials at a stationary source results in a net atmospheric contribution of biogenic CO_2 emissions. Although the framework does not reflect a full lifecycle assessment of all CO_2 emissions related to biogenic feedstock production and use, the framework provides a means to consider the role of the biological carbon cycle effects, including biogenic carbon and carbon-based fluxes, associated with biogenic feedstock growth, harvest, processing, and use. The methodology in this report includes technical elements that can be adapted to reflect a variety of policy scenarios based on key decisions by the user, including type of baseline (e.g., reference point or anticipated), time frame of the assessment (e.g., future or historical, 20, 30, 50, 100 years), feedstock categories (i.e., waste-, agriculture-, and forest-derived), and scale (e.g., state, regional, national). Many of the decisions are dependent on the user's goals and could be coupled with practical considerations, such as data availability and user type. As a result, the framework is designed to be flexible so that decisions on specific components can be made to accommodate different policy constructs. The types of decisions a user of the framework could encounter are identified throughout this report, along with related considerations and implications of those decisions.

The body of this report describes the scientific rationale for the framework, presents the equation and terms on which the framework is based, and discusses key issues that should be considered when applying the framework to a specific policy or program. It also discusses publicly available data sets that could be used in the framework, including the EPA's National Inventory of Greenhouse Gas Emissions and Sinks, the U.S. Department of Agriculture (USDA) National Resources Conservation Service's National Resources Inventory, the USDA Forest Service's Forest Inventory Analysis, and the Energy Information Administration's Annual Energy Outlook. Technical documentation is included in a set of appendices that present further detail on various elements of the framework and demonstrate how the framework could be applied through illustrative examples.

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1. Introduction

1.1. Purpose of this Report

This report presents a methodological framework for assessing the extent to which the production, processing, and use of biogenic material at stationary sources results in a net atmospheric contribution of biogenic carbon dioxide (CO_2) emissions. Biogenic CO_2 emissions are defined as CO_2 emissions related to the natural carbon cycle,[6] as well as those resulting from the production, harvest, combustion, digestion, fermentation, decomposition, and processing of biologically based[7] materials.

The intent of the framework is to evaluate biogenic CO_2 emissions from stationary sources that use biogenic feedstocks, given the unique ability of biogenic material to sequester CO_2 from the atmosphere over relatively short time frames through the process of photosynthesis. The framework focuses on changes in biogenic carbon-based stocks and related emissions and sequestration—known as carbon fluxes (including CO_2 and methane fluxes) – that occur (or are avoided) as a result of (1) feedstock growth and harvest; (2) processing, transport, and storage and use of a biogenic feedstock at the stationary source; and/or (3) the possible alternative fate of the biogenic feedstock materials if not used for bioenergy.[8] Although the framework does not reflect a full lifecycle assessment of all CO_2 emissions related to biogenic feedstock production and use, the framework provides a means to consider the role of the biological carbon cycle effects associated with biogenic feedstock growth, harvest, and processing. Figure 1 provides a simple graphic that shows the biogenic carbon pools and carbon-based flows that are represented within the framework.

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[6] The term "carbon cycle" is used to describe the flow of carbon (in various forms, for example, as CO_2) through the atmosphere, ocean, terrestrial biosphere, and lithosphere (IPCC, 2007a).

[7] Biologically based feedstocks, also referred to in this report as "biogenic materials," are non-fossilized and biodegradable organic materials originating from modern or contemporarily grown plants, animals, or microorganisms (including products, by-products, 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). These feedstocks do not include materials such as peat, coal, petroleum, natural gas, and other products that are derived from biologic materials but are considered non-renewable during the time frame relevant to policymaking (years to decades).

[8] The framework includes consideration of carbon cycle fluxes associated with or avoided by the conversion of biogenic materials at stationary sources. For completeness, biogenic carbon and carbon-based gases—carbon dioxide and methane—are included within the framework as applied to forest, agriculture, and waste sector-derived feedstocks. Throughout the report, the term "biogenic CO_2" is used to represent these carbon-based stocks and gases.

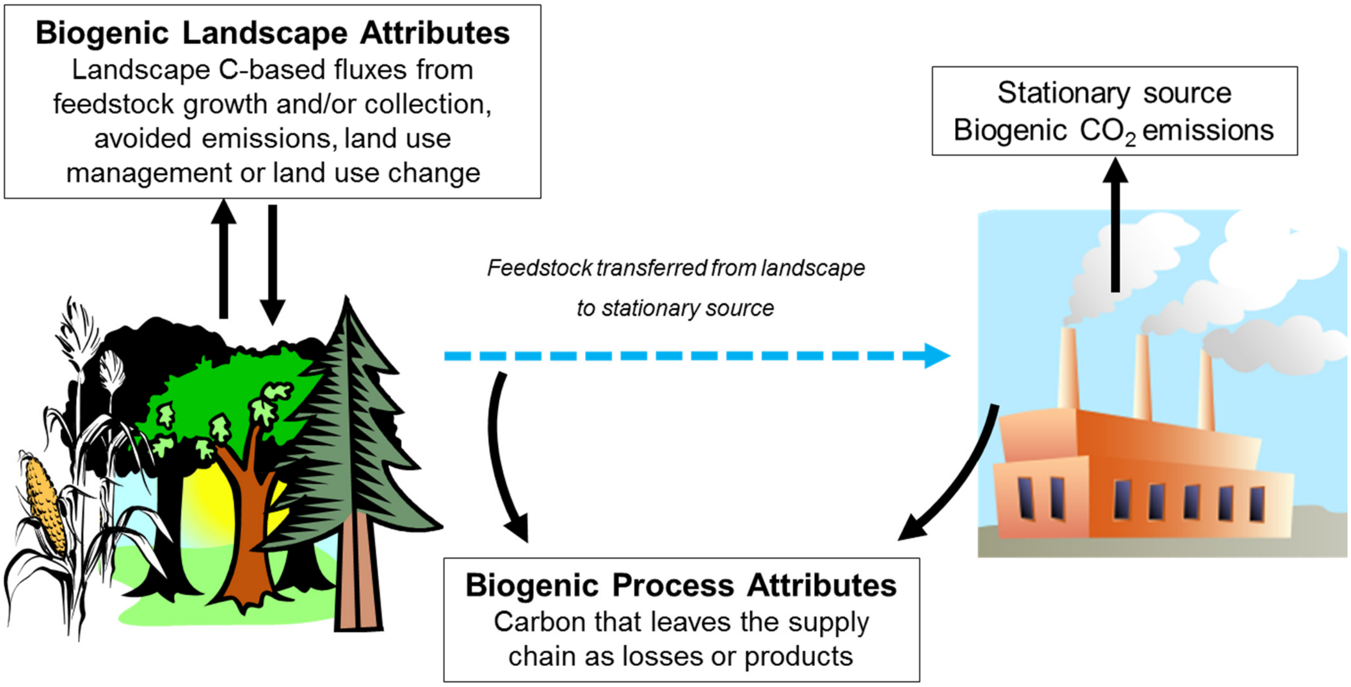

Figure 1. Diagram Illustrating the Basic Processes Addressed in the Framework. The framework addresses carbon fluxes associated with production, processing, and use of biogenic feedstocks. The solid, black arrows represent flows of carbon to and from the system of feedstock growth, harvest, and use. The dashed, blue arrow represents physical transfers of the biogenic feedstock from the production landscape to the stationary source (transport-related emissions such as tractor or train fuel are not included in the framework).

The framework presents an equation and discusses the terms of the equation, which are designed to account for the biogenic landscape and process attributes included in Figure 1 associated with feedstock production, processing, and use at stationary sources. Additionally, the framework identifies and discusses the key decisions for a user to make to inform the biogenic CO_2 flux assessment, including choice of baseline, temporal scale, feedstock categories, and spatial scale. A small number of illustrative examples based on hypothetical situations or case studies are provided to help demonstrate the types of results and implications of these decisions. Beyond the context of evaluating biogenic carbon and carbon-based fluxes associated with biogenic feedstock production, processing, and use at a stationary source, the framework is intended to be a tool that is useful to a variety of stakeholders and flexible so it can be adapted to fit the user's programmatic needs.

The framework is an analytical methodology for assessing the extent to which there is a net atmospheric contribution of biogenic CO_2 emissions from the production, processing, and use of biogenic material at stationary sources. EPA has not yet determined how the framework might be applied in any particular regulatory or policy contexts or taken the steps needed for such implementation. In addition, the framework and this report may be refined further by EPA based on further scientific or public review. For these reasons, the framework and this report are not a final agency action and do not establish or eliminate any regulatory requirements or create or remove rights or obligations enforceable by any party.

1.2. Background

On January 12, 2011, EPA announced a series of steps to address the treatment of biogenic CO_2 emissions from stationary sources, including a detailed study of the scientific and technical issues associated with assessing these emissions. In September 2011, EPA released a *Draft Accounting Framework for Biogenic CO_2 Emissions from Stationary Sources*.[9] The September 2011 report assessed various options for assessing biogenic CO_2 emissions from stationary sources and discussed related technical and scientific issues. This report was peer reviewed by members of the Biogenic Carbon Emissions Panel appointed by EPA's Science Advisory Board (SAB Panel).[10] In addition to various recommendations and comments on the draft framework report, the SAB Panel stated in its review that:

> Carbon neutrality cannot be assumed for all biomass energy a priori. There are circumstances in which biomass is grown, harvested and combusted in a carbon neutral fashion but carbon neutrality is not an appropriate a priori assumption; it is a conclusion that should be reached only after considering a particular feedstock's production and consumption cycle. There is considerable heterogeneity in feedstock types, sources and production methods and thus net biogenic carbon emissions will vary considerably. (p. 17)

The majority of the SAB Panel also found that it is not appropriate to use the Intergovernmental Panel on Climate Change (IPCC) national accounting methodologies to evaluate biogenic CO_2 emissions at individual stationary sources:

> The IPCC inventories, a static snapshot of emissions at any given point in time, are a reporting convention that has no associated connections to policies or implementation. These inventories do not explicitly link biogenic CO_2 emission sources and sinks to stationary sources, nor do they provide a mechanism for measuring changes in emissions as a result of changes in the building and operation of stationary sources using biomass. (p. 17)[11]

Though the SAB Panel did agree with some basic tenets of the 2011 draft framework report, they also found some technical elements lacking:

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

[10] The final peer review report from the SAB Biogenic Carbon Emissions Panel on the draft framework was published on September 28, 2012 (Swackhamer and Khanna, 2011). See SAB Review of the *Draft Accounting Framework for Biogenic CO_2 Emissions from Stationary Sources* (September 2011). Information about the SAB peer review process for the September 2011 draft framework is available at http://yosemite.epa.gov/sab/sabproduct.nsf/0/2F9B572C712AC52E8525783100704886.

[11] See Appendix A for further discussion of the IPCC guidelines for GHG emissions accounting from all sectors at the national level.

> The *Framework* is a step forward in advancing our understanding of how to account for biogenic emissions…. It covers many of the complicated issues associated with the accounting of biogenic CO_2 emissions from stationary sources and acknowledges that its choices will have implications for the estimates of CO_2 emissions obtained. These [choices] include those raised by SAB and discussed above, related to the choice of baseline, region selection and the averaging of emissions/stocks over space and time. However, the solutions offered in many cases, particularly those related to the use of harvested wood for bioenergy, lack transparency or a scientific justification. (p. 40)

Specifically, the SAB Panel recommended more consideration of different spatial and temporal scales, different baselines to better capture the additional effects of changes in biogenic feedstock use, broader discussions on leakage[12] and soil carbon implications, and the concept of regional feedstock-specific calculations and default assessment factor values (rather than individual stationary source-specific assessment factor calculations).

Various stakeholders from the environmental community, industry, academia, and government commented on the 2011 draft framework and SAB process and shared relevant research and data to inform EPA's evaluation of the scientific and technical issues associated with biogenic CO_2 emissions assessment. Many of these stakeholders focused on key issues similar to those included in the SAB Panel recommendations, although they did not always provide the same recommendations. For example, numerous stakeholders agreed with the SAB Panel's assertion that the framework should consider alternative fate pathways and methane emissions (especially in the context of waste-derived feedstocks like municipal solid waste [MSW]). Overall, various stakeholders submitted different recommendations on baseline approaches, temporal and spatial scales, and consideration of leakage with regard to these feedstocks.[13]

This report addresses central SAB Panel recommendations and stakeholder comments regarding the 2011 draft report.[14] Specifically, this report includes a more comprehensive discussion and analysis, including detailed technical appendices, on the following topics: (1) baseline approaches; (2) spatial and temporal scale decisions and implications; (3) inclusion of alternative fate analysis for certain feedstocks and methane; (4) leakage; and (5) illustrative regional feedstock-specific

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[12] This report uses the IPCC definition of "leakage," which is the indirect impact of a targeted activity in a certain place at a certain time on carbon storage at another place or time (IPCC, 2000).
[13] Stakeholder comments on the draft 2011 framework as well as the SAB Panel deliberations can be accessed at http://yosemite.epa.gov/sab/sabproduct.nsf/0/2F9B572C712AC52E8525783100704886. In addition, stakeholders have provided studies and analysis to EPA directly since the SAB has released their peer review.
[14] Some recommendations, such as "including a description of [the framework's] regulatory context and specifying the boundaries for regulating upstream and downstream emissions while implementing the regulation" and including "how possible regulatory measures under the Clean Air Act may relate to other policies that affect land use changes or the combustion/oxidation of products from the point sources that will release carbon or other greenhouse gases" (p. 42), are not reflected in this updated report because such parameters and boundaries may differ per application. Some program applications of the framework may include parameters and boundaries as appropriate to that program or policy.

calculations using existing data sources and models and resulting example regional biogenic assessment factor values.

1.3. Scientific Basis for the Framework

The framework is based on the fundamentals of the biological carbon cycle. The biological carbon cycle is the flow of carbon in various forms through the atmosphere, ocean, terrestrial biosphere, and lithosphere (IPCC, 2007a), and this transfer of carbon is generally called a carbon flux. [15] 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 sequester 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, 2007b; King et al., 2007). Carbon is returned to the atmosphere via respiration by plants and animals, industrial processes including combustion, wildfires, or decomposition. Carbon that is not returned to the atmosphere is stored on land in plants and vegetation, in soils, or in sediments and plants in fresh water or marine environments (IPCC, 2007b; King et al., 2007).

The biological cycling of carbon occurs on relatively short timescales. When cycled on the surface of Earth, carbon typically moves between pools on the scale of less than a year, to several years, to decades. For example, over the course of a single year, carbon can be removed from the atmosphere by herbaceous plant growth and returned to the atmosphere via decomposition. Over decades, carbon can be removed from the atmosphere by a growing tree and then released back to the atmosphere when the tree is burned or decomposes. Carbon may transit from living plants and trees to storage in litter, soil, and other pools prior to returning to the atmosphere (except in certain pathways and pools where carbon is stored longer term, for example, mineralized soil carbon).

In contrast to the relatively short timescale of the biological carbon cycle, 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 the natural processes described above. Instead, because of geologic processes, the carbon that accumulated in these deposits has been isolated from the active biological cycling of carbon to and from the atmosphere.[16] Without human intervention, carbon in fossil fuel reservoirs could remain isolated from the biogeochemical cycling of carbon long into the future.

Carbon is also stored in peat, which forms when plant material, usually in marshy areas, is inhibited from fully decaying by acidic and anaerobic conditions. Today's peatlands have formed over

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[15] The IPCC defines "carbon flux" as the transfer of carbon from one carbon pool to another in units of measurement of mass per unit area and time (IPCC, 2000). The term "flux" is used here to encompass biogenic carbon dioxide and methane emissions to the atmosphere, and removal of carbon from the atmosphere. Removal of carbon from the atmosphere is also referred to as carbon sequestration (EPA, 2014).

[16] Other processes cycle carbon on geological timescales, for example, carbon is vented by volcanoes, released from erosion of carbonate rocks (e.g., limestone), and deposited as sediments in marine and terrestrial basins (see IPCC, 2007b; King et al., 2007).

thousands of years, and the carbon in them has also remained largely isolated from the relatively short-term biological cycling of carbon. Peat is not renewable on policy-relevant time scales. [17]

Anthropogenic extraction and oxidation (e.g., combustion) of the carbon in fossil fuel reservoirs and peatlands returns this isolated carbon to the atmosphere and into the biogeochemical carbon cycle. Collectively, the combustion 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).

A particularly important foundation of the framework is the distinction between modern biological materials (e.g., non-fossil) that circulate carbon on policy-relevant time frames and materials such as fossil fuels or peat that circulate carbon on much longer geologic timescales. A key implication of this distinction is that the production and use of biogenic feedstocks and subsequent biogenic CO_2 emissions from stationary sources will not inevitably result in an increased net flux of biogenic CO_2 to the atmosphere within a policy-relevant time scale, unlike CO_2 emissions from combustion of fossil fuels.[18] Specifically, the net atmospheric contribution of CO_2 resulting from biogenic CO_2 emissions from stationary sources may differ from the contribution resulting from the same amount of fossil fuel CO_2 emissions from stationary sources.

1.4. Scope of the Framework

1.4.1. Biogenic Carbon and Carbon-Based Fluxes

The carbon and carbon-based fluxes evaluated in this framework include biogenic carbon-based emissions and removals. The former describes the transfer of carbon in the form of CO_2 and CH_4 from a reservoir[19] to the atmosphere, and the latter, known as carbon sequestration, describes the transfer or uptake of carbon in the form of CO_2 from the atmosphere to a reservoir. The framework examines shorter term fluxes of carbon that are anthropogenically induced by the production and use of biomass (see Figure 2, upper left quadrant). Although the framework addresses net atmospheric contributions of biogenic CO_2, it is critical to recognize that all CO_2 emissions contribute to the radiative balance of the atmosphere regardless of their origin, whether biogenic

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[17] For the purpose of this study, references to a policy-relevant time scale is the time frame of concern required for stabilization of atmospheric GHG concentrations to avoid "dangerous anthropogenic interference with the climate system" (UNFCCC, 1994). See http://unfccc.int/essential_background/convention/background/items/1353.php.
[18] For example, it is possible to harvest and consume biomass such that, when averaged over an annual growing cycle and only looking at the feedstock carbon itself (i.e., not considering any other carbon pools or biogenic carbon losses), 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) would be the same at the end of the year as it was at the beginning, and the net flux to (emissions) and from (sequestration) the atmosphere would be zero, averaged over a year. However, if the assessment starts with harvest and then the harvested feedstock is not replaced by growth (via replanting), then there will be a net increase in the amount of CO_2 in the atmosphere.
[19] A carbon pool is a system with the capacity to accumulate or release carbon, including the atmosphere, forest biomass, wood products, and soils. The term "reservoir" describes carbon pools other than the atmosphere (IPCC, 2000).

or fossil.[20] 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, and decomposition of biogenic material are the same as those of CO_2 released from any other process, including fossil fuel combustion. 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 is effectively the same.

Though "natural" and "biogenic" are sometimes used interchangeably in the context of fluxes, the IPCC distinguishes between them for greenhouse gas (GHG) inventory purposes (IPCC, 2006). Specifically, whether fluxes are "natural" or "anthropogenic" depends on the cause or origin of the emissions, whereas the carbon cycle time frame, as discussed above, determines whether fluxes are "biogenic." Biogenic emissions from the consumption of biogenic feedstocks at stationary sources would be classified as both anthropogenic and biogenic. See Appendix A for further discussion of the IPCC's approach to anthropogenic GHG emissions accounting.

1.4.2. Assessment Scope

The scope for assessing the net atmospheric contributions of biogenic CO_2 emissions can be narrow or quite broad, depending on the purposes and objectives of assessment. The framework is designed to assess the complex and shorter term biological carbon cycle fluxes associated with growth, harvest, transport, processing, and use of a biogenic feedstock at a stationary source. Thus, as presented in Figure 3, the assessment scope includes (1) the direct biogenic CO_2 emissions from a stationary source stack; (2) the carbon cycle effects of feedstock growth and harvest on the landscape where the feedstock is produced, as well as emissions associated with processing the feedstock for use at the stationary source. Depending on the application of the framework, an assessment may also include (3) biological carbon cycle effects related to leakage,[21] such as indirect land use change induced by displaced feedstock or feedstock substitute production.

[20] Radiative forcing is a function of the total concentration of CO_2 and other GHGs in the atmosphere and is not dependent on the origin of CO_2 (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, such as, for example, a change in the concentration of CO_2.

[21] See Part 4 and Appendix E for a discussion of leakage.

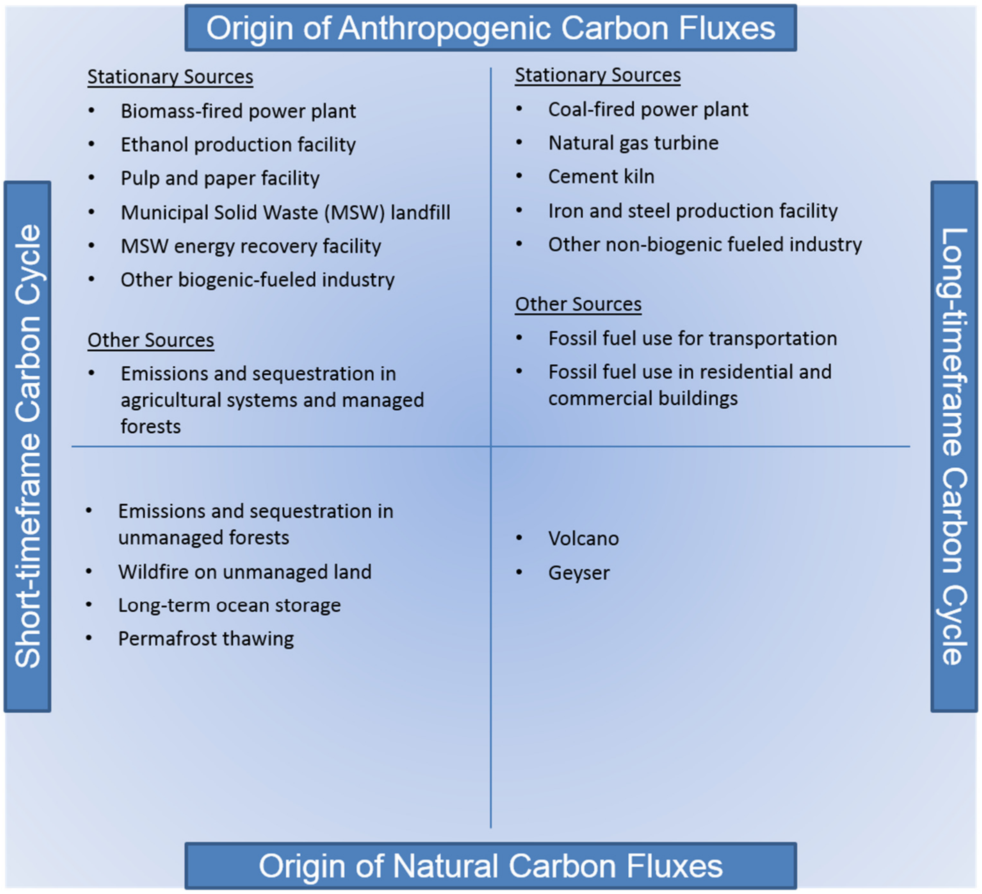

Figure 2: Various Carbon Flux Types and Time Frames. Carbon fluxes with the atmosphere can be defined in terms of (1) the long-term carbon cycle common to fossil fuels versus the short-term carbon cycle common to biogenic feedstocks and (2) natural versus anthropogenic origin of emissions.

Assessment scopes that extend beyond this framework include a full lifecycle analysis ([d] in Figure 3), which would take into account all upstream and downstream GHG emissions and sequestration related to feedstock production and use, including from all fossil fuel inputs used, for example, to power machinery used to harvest and transport biogenic feedstocks.[22] The framework provides a way to address a different, narrower issue: how to assess the extent to which the production,

[22] Lifecycle analysis, as defined in the RFS Regulatory Impact Analysis (EPA, 2010), 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 emissions assessments, lifecycle GHG emissions are the aggregate quantity of GHGs related to the full fuel life cycle (including direct emissions and significant indirect emissions such as emissions from land use changes), including all stages of fuel and feedstock production and distribution, from feedstock generation and extraction through distribution, delivery, and use of the finished fuel by the ultimate consumer, where the mass values for all GHGs are adjusted to account for their relative global warming potential (U.S Congress, 2007). See the following publications for the application of lifecycle analysis to biofuel-related GHG emissions: Berry et al., 1998; EPA, 2010; Heller et al., 2004; Heller et al., 2003; Keoleian and Volk, 2005; Mann and Spath, 1997; Spath and Mann, 2004; Spitzley and Keoleian, 2005. Other definitions and applications of lifecycle analysis may differ from those presented above.

processing, and use of biogenic material at stationary sources results in a net atmospheric contribution of biogenic CO_2 emissions. In this way, this framework aligns closer with typical fossil fuel stationary source analyses that generally do not account for emissions related to fuel extraction and transport. This framework also does not include analysis of temperature change impacts, radiative forcing, and social costs and benefits related to biogenic feedstock use for energy ([e] in Figure 3). Different applications of the framework could require evaluation of these factors, and they could potentially be incorporated into an analysis using the framework.[23]

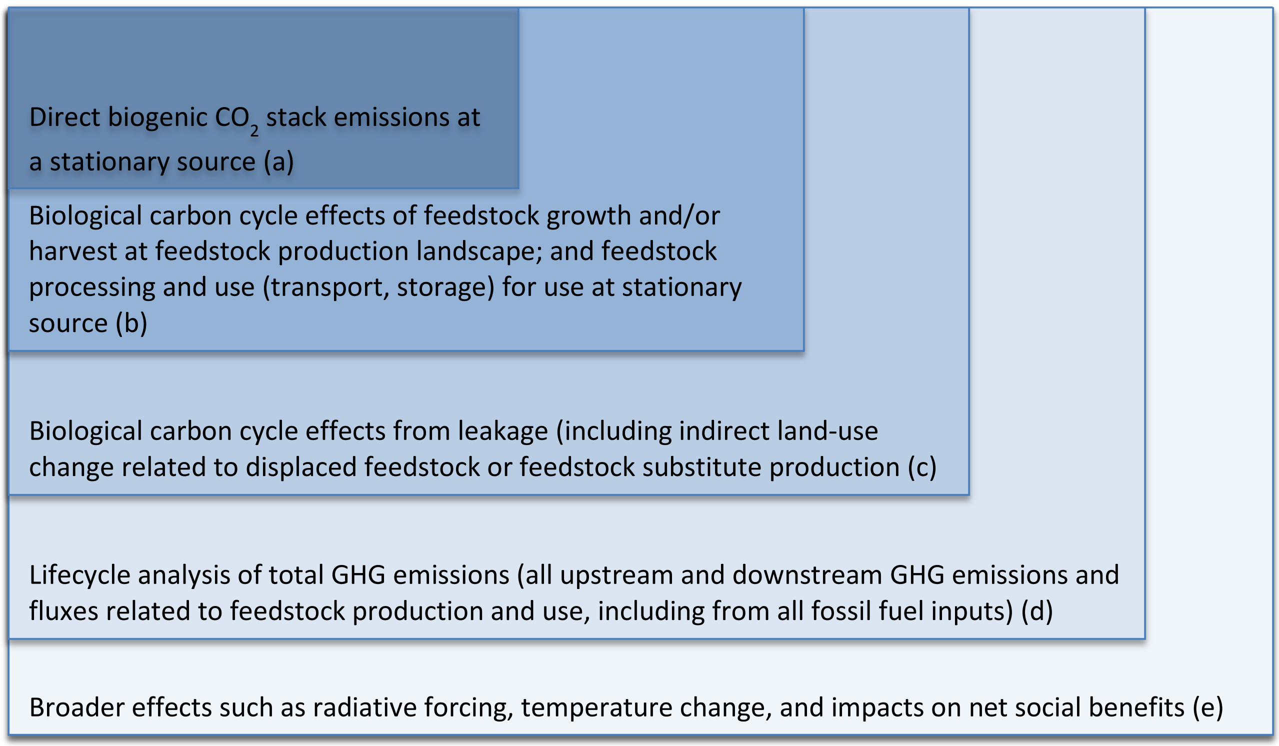

Figure 3: Potential Range of Assessment Scope. The framework focuses on the first three boxes (a through c). Though an equation term for leakage is included in the framework equation, a method for calculating leakage is not provided in this report. This framework does not include a complete lifecycle GHG emissions analysis (d) or include analysis of temperature change impacts, radiative forcing, and impacts on net social benefits (e).

1.4.3. Non-CO_2 Greenhouse Gases

The framework can take into consideration CH_4 emissions that are avoided when certain feedstocks, including waste-derived feedstocks, are used for energy.[24] CH_4 constitutes a significant

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[23] The scope of this framework does not assess or propose methods for assessing radiative forcing (IPCC, 2007b; Cherubini et al., 2011), changes in total atmospheric concentrations of CO_2 and other GHGs (IPCC, 2007b), potential impacts of increasing levels of atmospheric CO_2 (changes in precipitation, temperature, etc.), or the societal costs and benefits of mitigating GHGs (Interagency Working Group, 2010). See IPCC (2007a) for a discussion of potential climate change impacts and vulnerabilities.

[24] The amount of methane emitted from forest and agriculture-derived feedstocks combusted at a stationary source is typically small and depends, in part, on the engineering conditions at the individual stationary source (e.g., Lee et al., 2010).

portion of biogenic carbon-based fluxes associated with waste-derived feedstocks, including those from landfills or MSW.

In the context of agriculture- and forest-derived feedstocks, the framework can take into consideration landscape CH_4 emissions that are avoided when biogenic feedstock materials such as residues are collected and used for energy, instead of being open-burned or left to decay on the production landscape. However, in the United States, CH_4 is not a significant contributor to landscape carbon-based emissions related to the growth and harvest of biogenic feedstocks because most forest- and agriculture-derived feedstocks are produced in upland areas rather than in areas with higher moisture content, such as rice paddies or wetlands (see Figure 4).[25] These areas do not typically generate CH_4 emissions (Anderson et al., 2010) or, in some cases, have a small negative net CH_4 fluxes (EPA, 2013b).

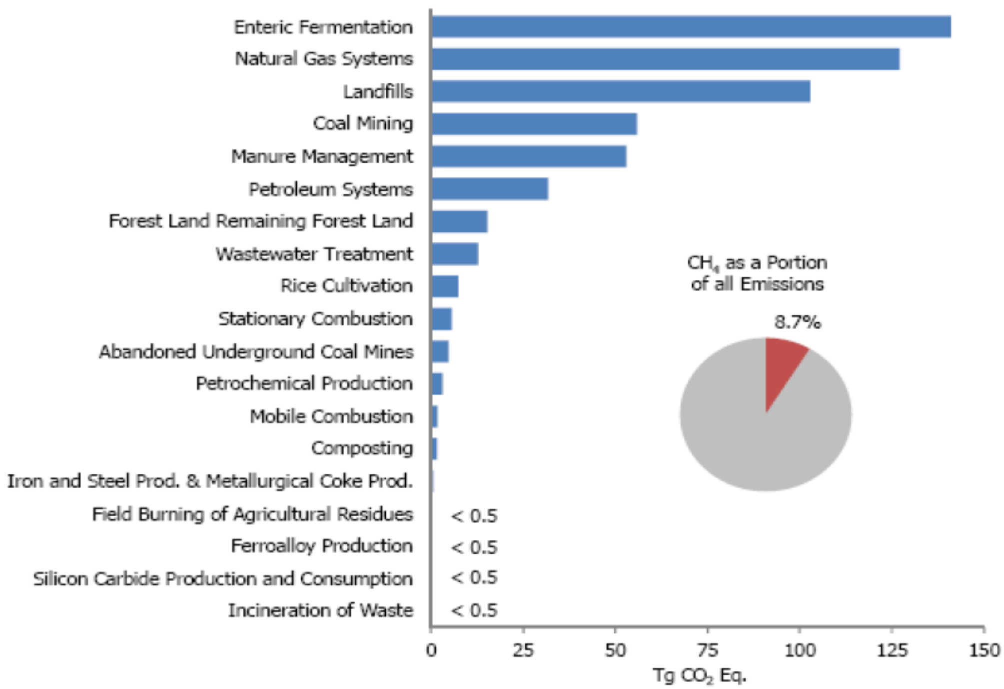

Figure 4: The Relative Size of Methane Emission Sources in the U.S. in 2012 (EPA, 2014).

Since the framework focuses specifically on biogenic carbon-based fluxes associated with feedstock production and use at stationary sources, it does not include an analysis of nitrogen or nitrogen dioxide (N_2O) emissions.[26] However, the framework equation is flexible and thus could be used to

[25] The largest sources of methane in the United States, other than waste management and rice production, are not typically associated with biogenic feedstock production and processing.

[26] Nitrogen is naturally present in the atmosphere as part of the global nitrogen cycle and has a variety of natural sources and forms. Nitrogen is essential for biomass growth and other important biological functions, and limited usable nitrogen can limit biomass growth. Anthropogenic nitrous oxide emissions result from agricultural fertilizer application, fossil fuel combustion, wastewater management, and industrial processes and interact with the global nitrogen cycle. However, nitrogen is not carbon-based and is not directly a part of the biological carbon cycle (though it is acknowledged that it does indirectly as a factor of biomass growth).

consider non-carbon-based gases in a specific program or policy application where the scope allows for and/or necessitates inclusion of non-carbon-based gases.[27]

1.5. Organization of the Report

The next section of this report, Part 2, presents the biogenic assessment factor (*BAF*) equation and defines the terms it includes. Part 3 discusses a variety of ways the equation could be applied using representative and/or customized landscape and process factors. Part 4 presents important technical aspects, such as baseline assessment method, temporal and spatial scales, leakage, and feedstock categorization, which require consideration when applying the framework for use in a specific policy or program. Part 5 discusses key issues that emerged in the course of designing the framework and highlights possible avenues for further exploration and improvement. Parts 6 and 7 include the glossary of terms used in the document and the list of references. Part 8 presents an outline of the technical appendices, which provide detailed background and illustrative case studies. Appendices A through G offer detailed discussion of the technical considerations used in the framework, including IPCC methods, temporal and spatial scale, feedstock categorization, process attributes, leakage, and an algebraic representation of the framework. Appendices H through M provide example applications of the framework, using publically available data applied in hypothetical scenarios, to generate illustrative values for the framework equation terms and assessment factors per different baselines, feedstock, and region combinations and other variations to the technical aspects of the equation. Appendix N provides an illustrative assessment of waste-derived feedstocks.

2. Biogenic Assessment Factor Equation

2.1. Purpose of the Equation and Biogenic Attributes Considered

This framework presents an equation, called the biogenic assessment factor (*BAF*) equation, which includes terms representing different aspects of the biological carbon cycle dynamics associated with biogenic feedstock growth, harvest, processing, and use at stationary sources. The equation is meant to serve as a tool that can be modified to meet the needs of policy or program applications that involve assessment of the net atmospheric contribution of biogenic CO_2 emissions associated with biogenic feedstock production, processing, and use at stationary sources.

The biogenic attributes related to feedstock production and use fall into two categories:

(1) Biogenic landscape attributes: biogenic feedstock carbon and carbon-based fluxes that are associated with the landscape where a biogenic feedstock is grown and harvested/collected, and/or those that are associated with avoided emissions from feedstock use. The biogenic landscape attributes associated with feedstock production include:

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[27] Appendix M includes a sensitivity run estimating the potential impacts of including N_2O for illustrative purposes.

- Net biogenic carbon sequestered or emitted through feedstock growth and removals on the feedstock production landscape;
- Avoided emissions associated with feedstocks that would have eventually decomposed or been burned on the production site if not removed or some other alternative fate;
- Net biogenic carbon emissions or sequestration from non-feedstock biogenic carbon pools on the production landscape associated with land use change (e.g., converting forests to agriculture) or land management or change in land management (e.g., harvesting practices); and
- Emissions associated with leakage, such as indirect land use change from displaced feedstock or feedstock substitute production.[28]

(2) Biogenic process attributes: biogenic feedstock carbon fluxes that occur during transit, processing, or use of the feedstock. The biogenic process attributes associated with feedstock processing at the stationary source include:

- Biogenic feedstock carbon that leaves the stationary source supply chain as losses during transportation, storage (decomposition), and processing; and
- Biogenic feedstock carbon embodied in products. Products could pass out of the supply chain and exit the stationary source either prior to use (e.g., lumber) or after use (e.g., ash, biochar).[29]

The inclusion of process attributes provides two benefits. First, process attributes allow for a complete mass balance calculation to understand the fate of the feedstock carbon. A mass balance approach allows for an assessment of (1) the proportion of biogenic feedstock carbon that enters the process; (2) the proportion of the feedstock carbon that passes through a stationary source as products; (3) the amount that is emitted to the atmosphere through losses during transport, storage, and processing; and (4) the amount that is emitted through the stack.

Second, inclusion of these process attributes allows the framework to reflect differences in physical properties across feedstocks, such as different responses to the applied storage conditions (e.g., temperature and/or moisture) and conversion processes. The quantity of post-process products, such as ash, is largely determined by the feedstock used (Hiltunen et al., 2008), the combustion process, and feedstock moisture content. Generally, biogenic feedstocks produce more post-combustion materials than fossil fuels due to different characteristics such as lower heating values and more moisture content in biomass.[30]

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[28] Indirect land use change is one form of leakage, which is the indirect impact that a targeted activity in a certain place at a certain time has on carbon storage at another place or time (IPCC, 2000).
[29] In specific applications of the framework, this process attribute category could be used to represent carbon capture and storage (CCS) if appropriate.
[30] For example, see the Biomass Energy Center's typical heating values of different fuels (www.biomassenergycentre.org.uk).

2.2. Overview of the Biogenic Assessment Factor Equation Terms

This section first presents an overview of the *BAF* equation and terms, each of which are explored in depth in the following subsections–starting with the primary terms of the equation, followed by the biogenic landscape attribute terms and then the process attribute terms. Landscape attribute terms are determined by feedstock type and geographic feedstock production site. Process attribute terms are primarily influenced by and thus may be evaluated by a combination of feedstock type, feedstock production region, and stationary source process.

Net biogenic emissions (*NBE*) represents the net atmospheric biogenic CO_2 contributions associated with biogenic feedstock production, processing, and use at a stationary source. *NBE* is calculated by multiplying the potential gross emissions (*PGE*) of the biogenic feedstock input when used at a stationary source by the feedstock's biogenic landscape attributes, and then by factors that adjust for biogenic feedstock carbon losses that may occur during storage, transport, or processing, as well as biogenic feedstock carbon that passes through the process as products instead of stack emissions.

NBE is calculated as:

$$\boldsymbol{NBE} = (\boldsymbol{PGE})(\boldsymbol{GROW} + \boldsymbol{AVOIDEMIT} + \boldsymbol{SITETNC} + \boldsymbol{LEAK})(\boldsymbol{L})(\boldsymbol{P}) \qquad \textbf{(EQ. 1)}$$

Where:

- *PGE* is the carbon content of the biogenic feedstock used by a specific entity (or generally consumed). This is a quantity could be measured or estimated at different points of assessment (e.g., at the boiler mouth, stationary source gate, feedstock production site, or at the stack: wherever the point of assessment needs to be. Thus, this term can have different values indicated by subscripts, representing different points along the supply chain).
- *(GROW + AVOIDEMIT + SITETNC + LEAK)* represents the landscape emissions effect. The landscape emissions effect is the sum of four unitless factors that relate the total biogenic carbon content of the feedstock grown at the feedstock production site, i.e., (*PGE* * *L*), to related landscape biogenic carbon pools.
  - *GROW* accounts for net feedstock growth on the biogenic feedstock production landscape (includes the specific feedstock carbon pool only).
  - *AVOIDEMIT* accounts for the avoidance of estimated biogenic emissions that could have occurred on the feedstock landscape without biogenic feedstock removal (e.g., avoided decomposition or burning) or per an alternative management strategy.
  - *SITETNC* accounts for the estimated total net change in non-feedstock carbon pools on the feedstock production site due to land use management or changes in land use and/or management associated with feedstock production.
  - *LEAK* accounts for the potential leakage associated with biogenic feedstock production and use at stationary sources.
- *L* is a unitless adjustment factor greater than or equal to one that represents biogenic feedstock carbon that leaves the supply chain (e.g., via transit or decomposition, deviated

for use as a product) between the feedstock production site and input into the conversion process at a stationary source. *L* scales *PGE*, as it was measured at the point of assessment, up to account for any losses during transportation or storage between the feedstock production site and the point of assessment. *PGE* times *L* is thus the carbon content of the biomass that was grown at the feedstock production site in order to deliver the quantity of feedstock measured at the point of assessment.

- *P* is a unitless adjustment factor between zero and one, equal to the share of the carbon content of the feedstock at the point of assessment that is emitted to the atmosphere by a stationary source (versus that which is embedded in products). In effect, this term also reflects the share of carbon that remains in products, that is not emitted to the atmosphere or is sold and eventually emitted to the atmosphere by a downstream user.

The *BAF* equation makes the estimate of *NBE* relative to the *PGE* that result from using a biogenic feedstock at stationary source. The *BAF* can be calculated by dividing *NBE* by *PGE*:

$$\boldsymbol{BAF} = \frac{\boldsymbol{NBE}}{\boldsymbol{PGE}} = \frac{(\boldsymbol{PGE})(\boldsymbol{GROW}+\boldsymbol{AVOIDEMIT}+\boldsymbol{SITETNC}+\boldsymbol{LEAK})(\boldsymbol{L})(\boldsymbol{P})}{\boldsymbol{PGE}} \quad \textbf{(EQ. 2)}$$

Therefore:

$$\boldsymbol{BAF} = (\boldsymbol{GROW} + \boldsymbol{AVOIDEMIT} + \boldsymbol{SITETNC} + \boldsymbol{LEAK})(\boldsymbol{L})(\boldsymbol{P}) \quad \textbf{(EQ. 3)}$$

The equations above are designed to transform a measurable or estimated quantity—the carbon content of biogenic feedstock used at the point of assessment (*PGE*)—into a quantity that cannot be directly measured—the net atmospheric biogenic CO_2 contributions of associated with the biogenic feedstock production, processing, and use, that the entity is responsible for or is generally consumed (*NBE*).

2.3. Primary Equation Terms

2.3.1. Net Biogenic Emissions (*NBE*)

The *NBE* term represents the net atmospheric biogenic CO_2 contributions associated with different stages of biogenic feedstock production, processing, and use at a stationary source. The biogenic landscape attributes (*GROW, AVOIDEMIT, SITETNC,* and *LEAK*, if included) and the biogenic process attributes (*L* and *P*) can be combined with *PGE* to estimate the *NBE* associated with the specific biogenic feedstock and stationary source process. *NBE* is expressed a unit of mass.

2.3.2. Potential Gross Emissions (*PGE*)

The *PGE* term represents the carbon content (expressed as unit of mass) of biogenic feedstock and is a quantity that could be measured or estimated at different points of assessment. The point of assessment may differ per policy or program application and could include sites such as the boiler mouth, the stationary source gate, the forest or farm production site, or the stack. Thus, the framework, which is designed to be flexible enough such that it can be applied to a variety of programs with different requirements, allows for identification and assessment of the biogenic feedstock carbon at different points along the supply chain, from the production site through the stationary source process.

Here is a simple example of how *PGE* could be evaluated at different points of assessment: the biogenic feedstock CO_2 potential harvested at a production site (point of assessment PGE_0) is 100 tons CO_2. Assume that there are no feedstock carbon losses and no pre-combustion products leaving the supply chain prior to entry into the combustion process (point of assessment PGE_1). Because there are no carbon losses between these two points of assessment, L = 1, and $PGE_0 = PGE_1$ = 100 tons CO_2. However, if the point of assessment is after the combustion process, the biogenic CO_2 emitted from the stack would be represented by PGE_S, which would be adjusted by P to reflect any post-combustion feedstock carbon in products (e.g., ash). Other examples of how L and P adjust *PGE* between the feedstock production landscape and later points of assessment are included in Appendix G.

2.3.3. Biogenic Assessment Factor (*BAF*)

The *BAF* is a unitless factor that represents the net atmospheric biogenic CO_2 contribution associated with using a biogenic feedstock at a stationary source, taking into consideration biogenic landscape and process attributes associated with feedstock production, processing, and use at a stationary source, relative to the amount of biogenic feedstock consumed. This term represents a ratio of the net biogenic carbon cycle effects from all stages of the growth, harvest/collection, processing, and use of a biogenic feedstock (i.e., the *NBE*) relative to the *PGE* of the biogenic feedstock consumed for energy (and resulting in stack emissions) at a stationary source. The purpose of deriving the unitless *BAF* value under this framework is to provide a universal metric that could be applied to assess the net atmospheric biogenic CO_2 contribution of biogenic feedstock use by a particular type of source without regard to the particular amount of feedstocks used. Once derived from assessing the carbon fluxes and mass balance associated with the production or use of a particular mass of feedstock in a specific type of process, the *BAF* value may then be applied to examine the net atmospheric contribution of any amount of the relevant feedstock used by a particular stationary source or type of stationary source for which the *BAF* value is representative. A discussion on interpreting *BAF* estimates is included later in this section, after descriptions of the landscape and process attribute terms.

2.4. Landscape Attribute Terms

The biogenic landscape attributes described below can be calculated in different ways, depending on the nature of the analysis being conducted and related parameters, such as the type of baseline being used or whether the analysis is retrospective (looking back in time) or prospective (looking forward in time). Thus, the calculation of each component, units used for calculations, and their values[31] can differ according to how the framework parameters are applied (e.g., baseline, spatial scale, temporal scale). The estimated biogenic landscape attribute terms are unitless values.[32] The text below provides some general examples of different ways to calculate these terms using different baseline approaches, in an effort to help explain what the terms represent and what kind

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[31] For example, the use of relative values compared with the carbon contained in the quantity of feedstock being used in the calculation (*PGE)*.

[32] However, the framework can be adapted to use units instead of unitless values as needed for a specific application.

of data they could include. Part 3 of this report discusses in detail the different types of baseline approaches, and the technical appendices include illustrative calculations of these terms using different regions, feedstocks, and baselines.

2.4.1. Net Growth on the Production Landscape (*GROW*)

The *GROW* term represents net feedstock growth (or removals) on the production landscape. This term includes biogenic carbon directly associated with the feedstock carbon pool. For example, if the feedstock under consideration is roundwood, then the *GROW* term would present the net change in biogenic carbon embodied in roundwood at the production landscape at the chosen scale, but it would not include changes in other carbon pools on the production landscape, such as soil carbon or detrital carbon (which are captured in another term, see *SITETNC*). The *GROW* term can be calculated in different ways, including with different baseline approaches.

For example, changes in the roundwood carbon stock (and related fluxes generated by feedstock growth and harvest) in a landscape could be evaluated between two points in time using historical data available for that landscape; this method would reflect a retrospective reference point baseline approach. Alternatively, a future anticipated baseline approach could be used to evaluate the estimated, or relative, difference between two (or more) future potential scenarios. This approach could use, for example, recently measured roundwood data as a benchmark of biogenic feedstock carbon on the landscape in question and then create projections of roundwood management activities (and related biogenic fluxes) over time using biophysical and economic modeling to reflect potential environmental and market conditions in business-as-usual (BAU) and alternative scenarios. If the feedstock is or is related to an annual crop with a one-year growing cycle (e.g., corn stover), the *GROW* term could equal 0, because during that one year the carbon sequestered during growth is equal to the amount removed from the landscape.

2.4.2. Avoided Emissions (*AVOIDEMIT*)

The *AVOIDEMIT* term accounts for the avoidance of estimated biogenic emissions that could have occurred on the feedstock landscape without biogenic feedstock removal (e.g., avoided decomposition or burning) or per an alternative management strategy (as in the case of, for example, waste-derived feedstock analysis). Examples include forest and agricultural residues that—in the absence of feedstock removal—would naturally decay or would be combusted onsite as part of the land management practice employed at the production site. In the case of waste-derived feedstocks like landfill gas and MSW, emissions could occur as part of the natural decay of the waste, with some of the carbon likely transformed to CH_4. This term focuses on the emissions fluxes related to the fate of the feedstock itself and does not include soil carbon implications of biogenic feedstock removal (this is captured within *SITETNC*, explained below).

The *AVOIDEMIT* term can be calculated in different ways, as necessitated per different baselines, feedstocks, and, in some cases, data availability. For example, with a strict interpretation of the retrospective reference point baseline, one cannot consider measured avoided emissions, because an assessment of avoided emissions requires a comparison between two scenarios (with and without the feedstock consumption), not just looking at observed data between two points in time. However, outside of a strict application of the retrospective reference point baseline approach, one can estimate avoided emissions by constructing a counterfactual baseline (a type of anticipated baseline) analysis of what action and related emissions occurred historically versus an alternative action and estimated related emissions, or one may use estimates from the literature pertaining to possible avoided emissions from certain actions (see Appendix H).

Using logging residues as an example, a future anticipated baseline approach could estimate the future potential biogenic carbon-based emissions that would have occurred if the logging residue was not used for energy and instead was open-burned or left to decompose. This approach derives an avoided emissions estimate by comparing a projected BAU future, in which the logging residues are open-burned or left on the forest floor at the harvest site, versus a projected alternative future, in which all or some portion of the logging residues are removed from the site due to increased demand for that feedstock.

As another example, MSW is a biogenic waste-derived feedstock composed of material that has been discarded, and the final disposition of this material must be managed in some fashion. If the waste-derived feedstock were not processed or used by a stationary source, it would have been managed through an alternative strategy with an alternative emissions pathway. Therefore, for waste-derived feedstocks, *AVOIDEMIT* represents the avoided biogenic emissions that could have occurred per an alternative management strategy instead of per the feedstock's use in bioenergy production, relative to biogenic feedstock consumption.

2.4.3. Total Net Change in Production Site Non-feedstock Carbon Pools (*SITETNC*)

The *SITETNC* term accounts for the estimated total net change in non-feedstock carbon pools on the feedstock production site due to land use management, or changes in land use and/or management associated with feedstock production. *SITETNC* explicitly refers to those carbon pools on the feedstock production other than the carbon in the feedstock, such as soil carbon, mineral carbon, below-ground biomass, detrital pools, and others as they relate to the feedstock in question. Thus, the carbon pools included in *SITETNC* do not overlap with those measured for the other terms in the framework equation (i.e., *GROW* and *AVOIDEMIT*).

Different land uses or land management systems can engender different average or equilibrium carbon stock values for the landscape carbon pools. Land use activities, including changing from one land use or management system to another, may result in a net change in overall carbon stocks (including soil carbon and other carbon pools on the landscape) over some period of time as the new use or system reaches equilibrium. If land use or management changes occur due to biogenic feedstock production, these changes can result in net emissions or net sequestration,[33] depending on the feedstock type, the previous land use activity, and extent of the change. Changes in land use or management can lead to altered emissions profiles that can occur over a period of years.

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[33] For example, if land under conventional crop cultivation with conventional till practices is converted to produce dedicated energy crops such as switchgrass, the resulting net landscape emissions could be negative, indicating higher levels of sequestration with switchgrass production (from increased carbon in the soil and root systems) than the previous land use practice.

Examples of land use or management changes that are captured in *SITETNC* might include planting a dedicated energy crop on land previously forested, switching from an annual to a perennial crop on existing agricultural land, or removing logging residues from forestland where such residues had previously been left on the forest floor and some portion of that carbon entered into the soil carbon and possibly also the mineral carbon pools.

For example, changing land use to produce a dedicated energy crop such as switchgrass on farmland previously used to cultivate wheat could result in increased soil carbon levels, due to the extensive root systems of switchgrass and the elimination of tillage. In this instance, the value for *SITETNC* would be negative, indicating a net sequestration of carbon resulting from the land use change. Conversely, if forest were cleared to plant switchgrass, this action would result in initial losses in soil carbon storage caused by disturbance during harvest, the lack of any further logging residues left to add to the soil carbon pool, losses from the understory carbon pools associated with forested lands, and a loss in standing carbon that would have occurred if trees were replanted instead of switchgrass. In this instance, the value for *SITETNC* would likely be positive, indicating a net emission of biogenic CO_2 resulting from the land use change.

Deriving a value for *SITETNC* for a feedstock can also differ according to the baseline approach used (as well as per the availability of data, spatial scale, and other factors). Using a retrospective reference point baseline approach, one could assess changes in measured non-feedstock biogenic carbon pools between two points in time. For example, if an increased amount of corn stover were removed from the production landscape between the reference points, measurements may show a decline in soil carbon pool levels. This decrease may have occurred because of the increased stover removal or possibly that practice in addition to other influences (such as changes in tillage rates or fertilizer application, for example). Using a future anticipated baseline approach, one could simulate the anticipated BAU conditions (in this case, corn stover remains on the landscape) versus an alternative projected scenario in which the stover is removed. This baseline approach allows for evaluation of the relative estimated impact of removing the stover on the landscape soil carbon pool.

2.4.4. Leakage Associated with Feedstock Production (*LEAK*)

The *LEAK* term represents the potential leakage associated with changes in biogenic feedstock production and use at stationary sources. The IPCC defines leakage as the estimated indirect impacts of a targeted activity in a certain place at a certain time on carbon storage at another place or time (IPCC, 2000). In the context of this report, leakage represents any biogenic carbon flux impacts outside of the biogenic feedstock production assessment boundary that can be attributed to the biogenic feedstock production activities (e.g., replacement of diverted crop, livestock, or forest products due to a change in land use from conventional products to biogenic feedstocks). Leakage can be positive—indicating increased emissions outside the assessment boundary (e.g., if unmanaged forests become managed forests in order to meet displaced market demand for traditional forest products)—or negative—indicating increased sequestration outside the assessment boundary (e.g., changes in biomass markets cause some landowners to convert idle cropland to forest, thereby increasing carbon stocks on the landscape).

One form of leakage—indirect land use change attributable to the production of a biogenic feedstock—can be challenging to quantify, because it often involves a number of complex socioeconomic dynamics (e.g., trade, market interactions) as well as biophysical impacts that occur outside of the biogenic feedstock production site and for which data may or may not be available. However, indirect land use change can result in significant emissions if it occurs at a large scale and involves conversion of land with relatively large preexisting carbon stocks.

The framework includes an equation term for leakage; however, the illustrative calculations presented in the appendices do not explicitly quantify leakage or provide a method to do so.[34] With the equation as described above in this section, it would be straightforward to include the effects of leakage if they were estimated in the context of a specific policy or program.

2.5. Process Attribute Terms

Feedstock carbon can exit the supply chain through process-specific factors other than as emissions from the stack. For example, losses during transportation of the feedstock, storage along the supply chain (e.g., due to decay), and handling can occur and can reduce the amount of biogenic feedstock available for processing or conversion. Representation of these supply chain losses allows for more accurate representation of the actual volumes of feedstock harvested to meet feedstock demand and related landscape attributes.

Feedstocks may be harvested specifically for energy production or for the production of products (e.g., wood products like paper or lumber) that may consume some portion of the feedstock, with either sale of the remaining feedstock material or for onsite conversion processes (e.g., bioenergy generation). The *NBE* equation allows for accounting of biogenic feedstock carbon in products that exit the supply chain before or after the conversion process but are not emitted from the stack during the conversion process. This feedstock carbon may pass through an entity to other end users (including secondary stationary sources) or possible longer-term carbon storage. Examples of products that may exit the supply chain prior to conversion at the primary stationary source include:

- Wood material in commercial products (lumber, wood pulp, panel products);
- Wood residuals sold/transferred to a separate stationary source for use as raw material or fuel;
- Bark sold to a separate (secondary) stationary source for fuel or other end users for mulch;
- Agricultural by-products (e.g., stover, stalks, straws, husks, hulls) sold/transferred to a separate stationary source for use as fuel; and
- Pulping by-products (tall oil, turpentine).

Examples of products that may exit the supply chain after conversion include:

- Distillers grains (from ethanol production);
- Ethanol; and

[34] See Appendix E for a discussion of the literature on leakage.

- Bottom ash, flyash, or biochar (e.g., materials containing unburned carbon).

The biogenic process attributes in the *NBE* equation perform two separate functions. First, they relate the quantity of feedstock measured at the point of assessment to the quantity that enters the supply chain at the feedstock production site (e.g., farm or forest) to deliver the measured amount of feedstock to a particular (primary) stationary source. This adjustment is accomplished by the *L* term, which accounts for losses that occur and products that are produced between the farm or forest and the point of assessment. The second function of the process attributes is to determine the share of the total net biogenic landscape emissions associated with the amount of feedstock that was grown at the farm or forest that exit the stationary source as stack emissions (and conversely, the remaining share that is associated with carbon that remains in products that could be passed to other uses or other entities). This adjustment is accomplished by the *P* term and accounts for products that are produced at any point in the supply chain and accounts for any losses that those products share responsibility for. The following sections describe the *L* and *P* terms in general, and there is detailed discussion of *L* and *P* in Appendix G and different illustrative equation pathways for these terms in Appendix F.

2.5.1. Feedstock Carbon Leaving the Supply Chain (*L*)

The *L* term facilitates the link between the quantity of feedstock entering the supply chain at the feedstock production site (e.g., farm or forest) and the quantity of feedstock measured at the point of assessment (e.g., the quantity received at the stationary source or the quantity of feedstock that enters the stationary source process). Specifically, the term tracks any differences in the mass of biogenic feedstock carbon between the feedstock production site and the point of use for energy at a particular stationary source (i.e., the feedstock conversion process).

L is a unitless adjustment factor greater than or equal to one that represents biogenic feedstock carbon that leaves the supply chain (e.g., lost via transit or decomposition, deviated for use as a product) between the feedstock production site and input into the conversion process at a stationary source. After harvest or collection at the production site, feedstock carbon could leave the supply chain for a specific source as physical losses (*LOSS*)[35] that occur during transportation to and storage and processing at a stationary source (e.g., decomposition during storage) or as products that exit the supply chain for a given source prior to the conversion process at that source (*PROD*, as further discussed in next section[36]). If feedstock carbon exits the chain for a specific source, this means that more biogenic feedstock was harvested/collected than is actually used in the conversion process at that stationary source.[37] Therefore, to reflect the production landscape biogenic carbon fluxes associated with the feedstock produced, these deviations of feedstock

[35] Different forms of physical losses (*LOSS*) could occur at different points along the supply chain. If multiple *LOSS* values are included, they would be reflected within the aggregated *L* term.

[36] Different products could be produced at different points along the supply chain and *PROD* represents the carbon within a product. If multiple *PROD* values are included, they can be subscripted and used to calculate the *P* term (which represents the carbon not embodied in products).

[37] As discussed later in this report, the collected carbon content that leaves a primary stationary source as product in the form of a fuel may be used by a secondary stationary source.

carbon need to be reflected in the biogenic carbon mass balance assessment. The *L* term differs from equation terms that address landscape biogenic attributes, which are based on feedstock type and the geographic location of the feedstock production landscape (such as *GROW*, *AVOIDEMIT*, and *SITETNC*). This term therefore is not dependent on landscape attributes but rather feedstock and process type.

L is represented as a ratio between biogenic feedstock carbon that enters the supply chain at the farm or forest and biogenic feedstock carbon measured at the point of assessment. *L* can be calculated by using measurements of products and losses taken along the supply chain prior to entry into the conversion process to relate biogenic carbon feedstock measured at the stationary source with the amount that originally entered the supply chain. Alternatively, *L* could be determined by dividing the harvested feedstock at the feedstock production site by the quantity entering the conversion process. For example, assuming no pre-conversion products, if the biogenic feedstock measures 100 tons CO_2e at the harvest site and then measures 90 tons CO_2e at the boiler mouth, *L* would be representing biogenic feedstock losses (via physical losses, decomposition, etc.) with a result of a positive 1.11.[38] For some feedstocks, it may be possible to generate representative values for *L* based on standard patterns of products and losses in the supply chain and/or related literature estimates.

For the purposes of the *L* term, any biogenic carbon that leaves the supply chain before being measured at the stationary source is assumed to be emitted to the atmosphere. (The *P* term will later account for any biogenic carbon that remains in products.) The biogenic feedstock physical losses are valued positively (using atmospheric accounting) because these losses represent an emission associated with procuring the biogenic feedstock for energy use. This value allows for recognition of the additional feedstock that was harvested and related additional landscape effects that may have occurred but were not actually consumed for energy by adjusting the landscape attribute equation terms upward.

2.5.2. Feedstock Carbon Embodied in Products (*P*)

The *P* term uses the share of biogenic carbon feedstock that is emitted out of the stationary source stack and the share that is embedded in products *(PROD)* to link the stationary source to the total net landscape emissions associated with the full amount of biogenic feedstock that entered the supply chain. The *P* term, therefore, allows the proportion of biogenic feedstock carbon that is not emitted from the stationary source stack but instead is embodied in products that exit the stationary source post-conversion (e.g., ash, ethanol, distillers grains, biochar) or pre-conversion (biogenic feedstock material in products that leave the supply chain between the feedstock production site and conversion) to pass through the mass balance accounting as carbon not emitted by the stationary source. It also allocates any carbon losses between the stationary source and any products produced after the losses occurred.

[38]1.11 = 100 tons harvested/90 tons input to bioenergy conversion process

The *P* term differs from equation terms that address landscape biogenic attributes, which are based on feedstock type and the geographic location of the feedstock production landscape (such as *GROW*, *AVOIDEMIT*, and *SITETNC*). The *P* term apportions biogenic feedstock carbon between products exiting the supply chain (non-emitted) and stack emissions and therefore is not dependent on landscape attributes but rather feedstock and process type.

Values for the *P* term could differ per feedstock type and stationary source process. Some feedstocks have various alternative uses and product possibilities due to their biophysical properties. Stationary sources will have different purposes in terms of product manufacture and/or energy production as well as different technical processes and efficiencies within those processes that may yield varying levels of pre- and post-conversion product materials.

For example, an ethanol plant transforms biogenic feedstock (e.g., corn) into ethanol fuel through a fermentation process. A portion of the carbon contained in the biogenic feedstock that is input to the conversion process forms the basis of the refined ethanol fuel. While fermentation results in process stack emissions of CO_2 from the stationary source, which may include some portion of carbon from the biogenic feedstock, the majority of carbon within the biogenic feedstock entering the stationary source fermentation process actually exits the stationary source not as stack emissions but as product (i.e., ethanol) or by-product (e.g., distillers grains).[39] Although the vast majority of the biogenic carbon embodied in the ethanol will be subsequently emitted as CO_2 by mobile emissions sources that use the ethanol as fuel, these "downstream" CO_2 emissions are not emitted by the stationary source that produced the ethanol. As a result, this portion of the biogenic feedstock carbon is not included in the final result when calculating the assessment factor for the biogenic CO_2 emissions from the ethanol facility.

As illustrated by the example above, the *P* term carves out the carbon contained in biogenic feedstock carbon that is not emitted from the stationary source stack but passes through the stationary source supply chain versus the biogenic carbon that it emitted from the stack; however, the carbon embodied in products leaving the stationary source may be subsequently used by another stationary source. Thus, the biogenic carbon stored in products from the producing or primary stationary source could in turn be considered as a feedstock (secondary use feedstock) input to a different stationary source (secondary stationary source) conversion process for energy.

Using sawmill mill residues that are sold to a separate stationary source as an example, if a secondary stationary source uses the mill residues procured from the primary stationary source (the sawmill in this example) as biogenic input for energy, then the mill residues could be considered a biogenic feedstock and the framework could be applied as necessary. However, those emissions from the secondary stationary source that uses the mill residues for energy are not

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[39] Some secondary products generated during production of primary products, such as distillers grains created during ethanol production, currently have alternative non-energy market uses, such as livestock feed. If, however, distillers' grains were instead used for energy at the stationary source, they would likely be considered a biogenic feedstock input and thus may require assessment with the framework.

included among the biogenic CO_2 emissions from the primary stationary source that produced the biogenic feedstock (mill residues).

Figure 5 includes the landscape and process attributes as reflected by the specific equation terms within the simple flow diagram graphic presented in Figure 1 above. The landscape attributes are defined by the initial point of assessment or the feedstock production site. Calculation of all remaining equation terms is predicated on emissions changes on the landscape. That is, each unit of biogenic CO_2 transferred from the landscape to the stationary source is adjusted to reflect net emissions on the landscape that occurred due to the growth and harvest of that feedstock. As Figure 5 shows, once the primary feedstock is harvested, biogenic process attributes can be evaluated at various points of assessment (both outside of and within the stationary source), and these terms are used to further adjust the net biogenic emissions that occur when the feedstock is converted to energy.

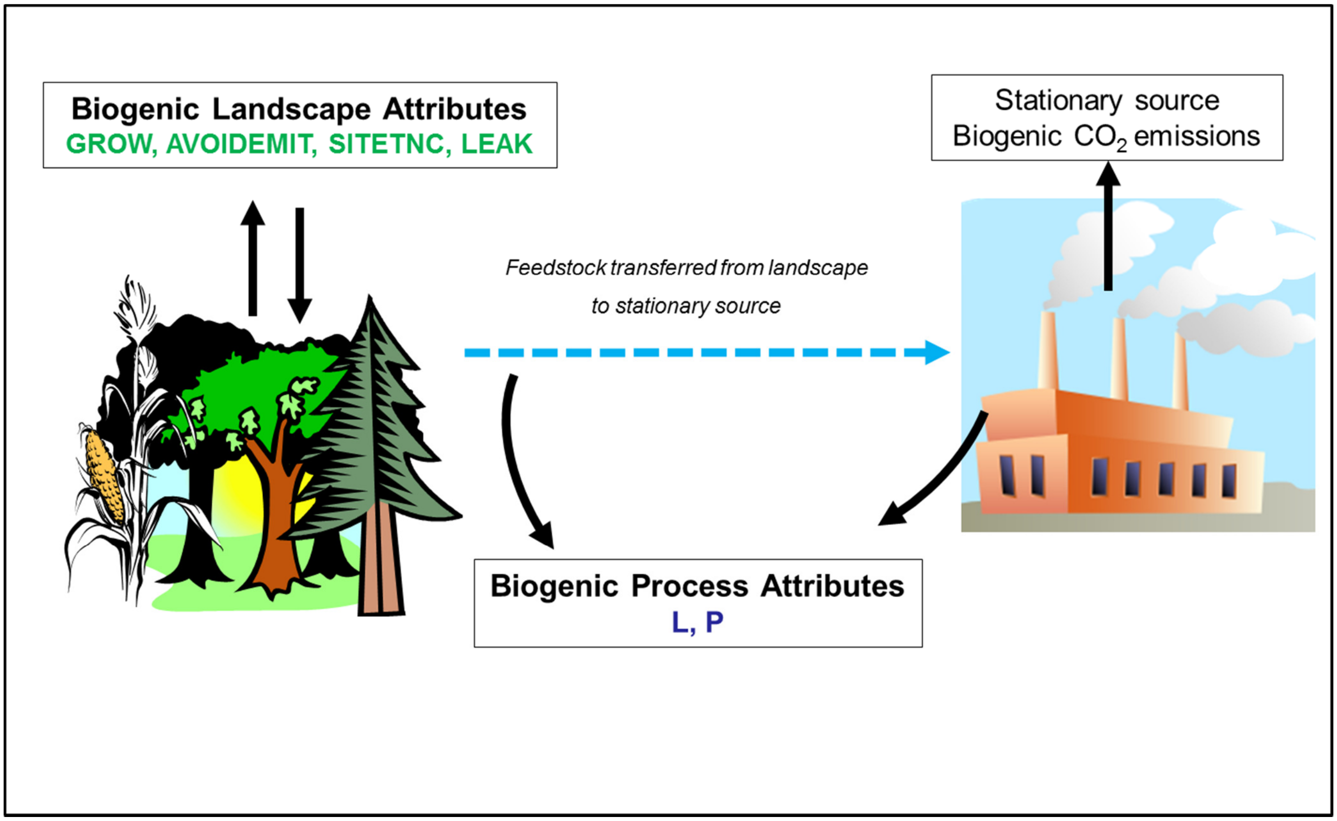

Figure 5: Diagram with Equation Terms Included. This figure is the same as Figure 4 except that in addition to illustrating the basic processes (i.e., biogenic carbon and carbon fluxes) addressed in the framework, this graphic also includes the equation terms that represent each of these basic process elements. The framework addresses biogenic carbon flows and fluxes associated with the production, processing, and use of a biogenic feedstock, including biogenic carbon impacts at the production landscape (*GROW, AVOIDEMIT, SITETNC*) as well as indirect impacts on landscapes other than the production landscape (*LEAK*); biogenic feedstock carbon losses during transport, storage, and processing of the feedstock (*L*); and biogenic feedstock carbon that is embodied in products that exit the supply chain or stationary source in means other than the stack (*P*).

2.6. Interpreting the Biogenic Assessment Factor

A policy or program could define and interpret the *BAF* results differently. For the purposes of this report, the *BAF* results can be interpreted as follows:

- A *BAF* of 0 means that 0% of the direct biogenic CO_2 emissions at a stationary source contribute additional biogenic CO_2 to the atmosphere—as compared with the baseline or reference condition—due to biological carbon cycling associated with feedstock production and use. In other words, changes in net biogenic CO_2 emissions and sequestration from biological carbon cycle processes and other offsite and process factors exactly offset the direct biogenic CO_2 emissions from the stationary source.
- A *BAF* of 1 means that 100% of the direct biogenic CO_2 emissions at a stationary source contribute additional biogenic CO_2 to the atmosphere—as compared with the baseline or reference condition—due to biological carbon cycling associated with feedstock production and use. In other words, biological carbon cycle processes and other offsite and process factors do not counterbalance any of the direct biogenic CO_2 emissions from the stationary source.
- A *BAF* value between 0 and 1, such as 0.2 or 0.5, means that biological carbon cycle effects related to biogenic feedstock growth, harvest, and use counterbalance a proportion of the direct biogenic CO_2 emissions from a stationary source (e.g., a 0.2 *BAF* means a net atmospheric contribution of 20% of the direct biogenic CO_2 emissions, while the remaining 80% is counterbalanced by landscape and process attributes).
- A negative *BAF* value, such as −0.2, means that the biological carbon cycle effects of biogenic feedstock growth, harvest, and use more than fully counterbalance the direct biogenic CO_2 emissions at the stationary source. Negative values represent an emissions reduction that occurs as the result of a stationary source's use of a biogenic feedstock. In this case, 20% more CO_2 is sequestered (or 20% more CO_2 emissions are avoided) as a result of stationary source use of a biogenic feedstock than is directly emitted by a stationary source.
- A *BAF* value greater than 1 means that the biological carbon cycle effects related to biogenic feedstock growth, harvest, and use result in a net CO_2 emissions increase, over and above the CO_2 emissions coming directly from the facility. For example, where direct land use change causes a substantial decline in carbon stocks on the landscape, or where leakage effects are included and found to be substantial, a *BAF* value may be greater than 1.

When all the equation terms are included, the estimated value of the *BAF* depends on the relative magnitudes of *NBE* and *PGE*. Higher values of *NBE* that approximate or exceed *PGE* lead to larger *BAF* values. Smaller values of *NBE* will result in small or negligible *BAF* values.

2.7. Possible Applications of the Biogenic Assessment Factor

The *BAF*, or elements of the *BAF* equation, could be applied in various policy scenarios. For example, a possible scenario may include calculating *BAF* values that may be used to determine whether to regulate direct biogenic CO_2 emissions from a stationary source. The framework could also be used to calculate an adjusted CO_2 emissions value at a stationary source by multiplying a *BAF* value by the direct emissions of biogenic CO_2 from the individual stationary source. To conduct these calculations, the framework equation and its terms may need to be adjusted or modified to accommodate only the specific parameters required for a particular application. For example, if an application of the framework is limited to an assessment of the environmental conditions of the landscape, the equation may only include use of the landscape attribute terms (*GROW*, *AVOIDEMIT, SITETNC*, and *LEAK*).

3. Representative and Customized Approaches to Landscape and Process Attributes

This section describes three ways biogenic assessment factor equation terms and *BAF*s could be used: a "representative factor" approach, a "customized factor" approach, and a hybrid approach. For each approach, this section discusses an example of how a program or policy might apply the approach to calculate *BAF* equation teams and *BAF* values. These approaches are for illustrative purposes only and not meant to be prescriptive or specific to any particular policy or program.

3.1. Representative Factor Approach

A representative factor approach could include pre-calculated, representative *BAF* values for specific feedstocks that take into account the landscape attributes and process attributes associated with that feedstock. Specifically, this approach could use an assessment of the biogenic landscape attributes (based on feedstock type and production site/region where the feedstock is produced) as well as the process attributes (based on the type of stationary source process and types of biomass handling such as transport and storage) to generate generally applicable values for those attributes. These representative factor values could be calculated using various spatial and temporal scales, baselines, and feedstock and process types as needed, and could be presented in a simple format (e.g., look-up tables). Using the representative factor approach, stationary sources would not need to make case-specific measurements and calculations of carbon stocks and fluxes for each term in the *BAF* equation in order to calculate a *BAF* for each feedstock used.

The representative values generated through this approach could require updating every 5 to 10 years to ensure that the values reflect updated data, including measured changes to biogenic landscape attributes, changes in process technologies, improvements in carbon measurement technologies, and other information necessary to update tools and methods used to calculate the representative values.

Using the representative factor approach, the following information would likely be needed by users to calculate a *BAF* value:

- Type of biogenic feedstock;
- Region where the feedstock was produced;
- Type of stationary source process;
- Transportation and storage methods and duration of feedstock storage; and
- Measured or estimated amount of feedstock used or stack emissions.

3.2. Customized Factor Approach

A customized factor approach would enable stationary sources to calculate their own values for each of the terms in the *BAF* equation, rather than using representative values as discussed above. Under this approach, the biogenic landscape and process attributes would be calculated using parameters specific to the specific stationary source using a specific biogenic feedstock.

For landscape attributes, a customized factor approach could require calculation of site-specific values for equation terms that characterize the distinct landscape where a feedstock is produced and harvested. For example, a stationary source would likely need information from the forest landowner regarding forest growth and removals to calculate a value representing net feedstock growth on the production landscape. The stationary source may also need data on delivered quantities of biogenic feedstock, as well as any biogenic feedstock losses that occur while the feedstock is being transported or stored prior to use.

A number of technical and implementation issues would need to be addressed to implement a customized factor approach, including:

- Identification of appropriate data collection approaches for carbon stocks and carbon fluxes, by feedstock type and framework equation term;
- Identification of the appropriate level of data quality (possibly including statistical sampling protocols and acceptable standard error thresholds);
- Development of protocols for identifying the distinct landscape where a biogenic feedstock is produced, including identification of landownership and management practices;
- Development of protocols to validate monitoring and reporting, if necessary[40]; and
- Development of protocols, or modification of existing protocols, if needed to track a biogenic feedstock from the specific landscape where it was produced to the stationary source where it was used.[41]

A customized factor approach may provide for greater flexibility, and possibly greater accuracy, in instances where a stationary source can identify the specific land base where a biogenic feedstock was grown and harvested. Such an approach would also allow a stationary source to provide greater specificity about the process attribute-related biogenic CO_2 fluxes that occur onsite at a stationary source, as a result of biogenic feedstock storage and processing. This approach would allow a stationary source to apply detailed knowledge about specific stationary source technology

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[40] For example, this might involve protocols for independent verification of measurement and reporting, including protocols for accreditation of verifiers.

[41] It should be noted that a representative feedstock approach might also need to employ a limited chain-of-custody tracking process in certain instances. For example, tracking might be needed to identify a biogenic feedstock's source region, considering the potential for inter-regional transportation of feedstocks. Tracking might also be necessary where the feedstock type is not easily identifiable from visual inspection or chemical analysis alone. For example, the origin of wood chips may not be easily identifiable through visual inspection alone, because wood chips could be sourced from different woody biomass feedstocks, such as roundwood, forest residues, or mill residues, or might contain a mixture of woody biomass from multiple feedstock types or source regions.

and operations that may differ from assumptions applied in developing representative factor values for process attributes.

3.3. Hybrid Approach

Depending on the availability of information, a combination of both approaches described above could be used. A hybrid approach could involve using a customized factor for some of the terms in the *BAF* equation and a representative factor for the other terms. For example, consider a stationary source that uses logging residues from the Northeastern U.S. The stationary source could use the representative factor values provided for landscape attributes associated with logging residues from the region (equation terms *GROW, SITETNC*, *AVOIDEMIT*, and *LEAK*) along with customized factors for process attributes that the entity calculates from information on its processes. Conversely, representative factors could be provided for general stationary source processes, and the stationary source could calculate customized factor values for landscape attributes associated with the landscape producing the logging residues it uses.

4. Technical Considerations

The sections below describe key technical and methodological components to consider when evaluating biogenic CO_2 fluxes related to a stationary source's use of biogenic feedstocks:

- Baselines
- Temporal scale
- Spatial scale
- Leakage
- Feedstock categorization

The implications of making particular choices with respect to each of these key issues are discussed below, and the technical appendices provide illustrative examples of how these considerations might be applied in practice.

4.1. Baselines

In basic terms, defining a baseline creates a foundation for comparing changes to a system over time or at different points in time.[42] A baseline can be constant over time or it can vary with time to represent some measured, anticipated, or desired change. However, the choice of baseline largely depends on the analysis or application at hand. The choice of which baseline approach to use also

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

depends in part on the time frame in which the analysis should take place, the context in which the approach is applied, and the available data.

The framework methodology involves a baseline against which the emissions and sequestration associated with the production, processing, and use of biogenic feedstocks at stationary sources can be estimated and analyzed. Ultimately, the determination of which baseline to use can influence the outcome of the assessment and will likely depend on the specific context in which the framework is applied.

This framework examines two baseline approaches, although other baselines could be used when applying the framework. The first baseline approach is the reference point baseline, which assesses the estimated net change in biogenic CO_2 fluxes and/or carbon stocks between two points in time (Fargione et al., 2008; UNFCCC, 2009). The second baseline approach, the anticipated baseline, assesses the estimated net changes of biogenic CO_2 fluxes and/or carbon stocks between two scenarios at the same specified point in time. The anticipated baseline approach estimates the difference between a BAU scenario and an alternative counterfactual scenario that includes changes in environmental, economic, and/or policy conditions (Searchinger et al., 2009; Sohngen and Sedjo, 2000).

The reference point and anticipated baseline approaches can both be used for prospective or retrospective analyses. A prospective analysis assesses the potential impact of a particular policy or change in biomass use on future biogenic CO_2 fluxes and/or carbon stocks,[43] while a retrospective analysis can examine the impact that an existing policy or biomass utilization practice has made on net biogenic CO_2 fluxes in the past. Prospective analyses commonly use the anticipated baseline approach to compare two future scenarios. A reference point baseline may also be used in a prospective analysis that compares modeled alternative future biogenic CO_2 fluxes to modeled or observed biogenic CO_2 fluxes at an earlier point in time. Retrospective analyses can use the reference point approach to compare current or recent biogenic CO_2 fluxes to historical biogenic CO_2 fluxes, because this approach allows for the possibility of using only observed data. However, an anticipated baseline may also be used in a retrospective analysis comparing current/recent biogenic CO_2 fluxes with modeled counterfactual current/recent biogenic CO_2 fluxes.

The two baseline approaches discussed above can provide useful insights in the assessment of biogenic CO_2 fluxes. There is no single correct answer for which baseline to choose, because different baselines help answer different questions. The sections below describe how reference point baselines and anticipated baselines can be constructed and applied and discuss the implications of using either baseline approach in the framework.

4.1.1. Reference Point Baseline

The reference point approach can be applied in situations that seek to measure what has or has not occurred on the landscape between two different points in time. The reference point baseline

[43] The rest of this section uses the term biogenic CO_2 fluxes as the unit of evaluation to represent changes in carbon stocks as well as methane fluxes.

approach seeks to answer the question, "*Is there more or less carbon stored in the system (e.g., at the biogenic feedstock production site or region) at the end of an assessment period than there was at the beginning?*" This approach allows for estimation of net carbon changes between different points in time. It establishes as the baseline the carbon stock (or carbon-based flux) on a given land base (i.e., total stocks of carbon stored in vegetation and soils) at a given point in time (or over a given time interval). Land based carbon stocks or fluxes can then be evaluated against this reference point.

A reference point approach could be applied in a retrospective analysis using observed current (time t) carbon stocks and observed past (time t−1) carbon stocks, or in a prospective analysis, using future (time t+1) values instead of observed values. One potential benefit of the retrospective reference point baseline is that it enables the user to rely on historic carbon stock data, which may be available for selected feedstocks (e.g., U.S. Forest Service Data for roundwood). Some of the illustrative *BAF* calculations provided in the technical appendices of this report apply the reference point baseline retrospectively, relying primarily on historical observed or modeled data or related estimates from the literature. To develop the baseline under this retrospective reference point approach, it is appropriate to look at carbon stocks in the present and/or in the recent past to see how those stocks change between the two points of evaluation.[44]

There are some limitations with using this approach. For example, land use, land use change, and forestry (LULUCF) data are often more uncertain than data from other sectors (e.g., energy) due to the complexity of the natural systems and the variety of anthropogenic uses and activities involved. Also, although tools and methods to monitor and model these systems exist, land-based ecosystems are ever changing and differ across different parts of the country, making it difficult to measure them regularly and robustly. Challenges can result from numerous factors, including insufficient data or information about a physical or economic process being evaluated, model/data specification, inherent statistical uncertainties, etc. Other limitations with the reference point baseline approach stem from gaps in data coverage (e.g., some data sets are not national or do not exist for certain carbon pools or management practices), size of samples, and frequency of samples. Furthermore, when conducted at the regional level, the impacts of external drivers on the biogenic carbon fluxes on the production landscape may not be identifiable.

In addition, other limitations may result from using the retrospective reference point baseline approach, including the inability to attribute landscape biogenic carbon fluxes directly to stationary source use, or to assess additionality. Additionality is a criterion for assessing whether an activity has resulted in biogenic carbon emission reductions or removals in addition to those that would have occurred in the absence of the activity. Additionality can be gauged as the difference in net atmospheric CO_2 emissions with and without changes in biogenic feedstock use (Murray et al., 2007). If the goal of an analysis is to assess additionality (i.e., what would have happened in the absence of increased/decreased biomass use) or the potential impact of a marginal user of biogenic

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[44] This baseline could include a value from carbon stocks in one year or an average over a range of years.

feedstocks, the use of the retrospective reference point baseline (as defined here) would not be the most appropriate choice because it does not include comparison with a counterfactual scenario.[45]

Unless conducted at a small scale, the retrospective reference point approach does not show the extent to which the increased or decreased use of a biogenic feedstock at a specific stationary source is contributing to the net carbon stock change.

At larger scales like, for example, the regional level, the retrospective reference point approach can indicate whether there has been a net change of the feedstock carbon stock within a given region. If historic data are readily available to assess the difference in regional feedstock carbon stocks between two points in time, then the reference point offers a practical method for determining if the area where the feedstock is harvested is a source or a sink (as discussed in Appendices H and I). In certain contexts, this observed carbon stock change can serve as a proxy for the net emissions contribution of biogenic feedstock production and harvest. However, relevant historic data may not exist for retrospective assessment of particular feedstocks (such as agricultural by-products or energy crops not currently grown at commercial scale).

The retrospective reference point approach is presented in the appendices of this report as an example to show the functionality of the framework using historical data on regional land carbon stock changes to assess changes in net carbon stocks between two points in time retrospectively. These illustrative applications of the retrospective reference point baseline use U.S. LULUCF and agriculture data to establish feedstock- and region-specific reference carbon stocks to estimate landscape changes in carbon stock pools associated with the production and use of a specific biogenic feedstock over a historic time frame. These changes are reflected in the illustrative landscape attribute values presented in Appendix H and the case studies in Appendix I.

4.1.2. Anticipated Baseline

The anticipated baseline approach provides a means to gauge the incremental impact of biogenic feedstock production and use for energy, especially in the case of forest-derived feedstocks or feedstock production that causes land use and/or management changes (e.g., afforestation to provide wood for energy). The anticipated baseline approach seeks to answer the question, *"Is more or less carbon stored in the system over time compared to what could have been stored in the absence of changes in biogenic feedstock use?"* This approach allows for estimation of the carbon stock levels (and associated carbon benefits or losses) that might have existed over time in the absence of biogenic feedstock use, or what could have happened under an alternate fate (i.e., a counterfactual scenario to what actually took place, which is the basis of how avoided emissions can be estimated).

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[45] The SAB Panel found that the reference point approach was limited in that it could not identify and assess additionality: "[the reference point] approach is not adequate in cases where feedstocks accumulate over long time periods because it does not allow for the estimation of the incremental effect on greenhouse gas emissions over time of feedstock use. To gauge the incremental effect on forest carbon stocks due to the use of forest-derived woody biomass…, an anticipated baseline approach is needed" (SAB Panel peer review, p. 33).

Typically, applications of an anticipated baseline first establish a BAU baseline scenario,[46] a reference level that establishes historic or simulates future anticipated biogenic feedstock use and related environmental and socioeconomic conditions and impacts along a specified time scale. The BAU baseline estimates are then compared with an alternative scenario of changed (e.g., increased or decreased) biogenic feedstock demand. The resulting difference between these scenarios can indicate the possible impacts of biogenic feedstock use.

The anticipated baseline approach differs from the reference point baseline approach in several key ways, including:

- The anticipated baseline is a comparison between two distinct scenarios, not two points in time. Although there is a time element to the anticipated baseline approach, the basis of comparison for evaluating emissions changes is the difference between two modeled scenarios.
- Because it is a comparison between scenarios, the anticipated baseline approach also allows for the evaluation of additionality (landscape emissions with and without additional feedstock harvest).
- The anticipated baseline approach relies on models that can project alternative futures, whereas a reference point approach can only require historic observed or modeled data.

A challenge with an anticipated baseline approach lies in how to define what would have been expected to occur in the BAU or counterfactual scenarios. In a retrospective application, the challenge is to consider what the counterfactual "without biomass" scenario would have been, after the period has ended (e.g., would more or less biomass have been used than what actually was used). In a prospective application, one would need to simulate the future BAU biomass consumption and future socioeconomic and environmental conditions (including carbon stocks and fluxes related to the biomass consumption) as well as the counterfactual scenario. These baselines could be established through various means, such as dynamic modeling or extrapolation of historic trends, each with different related kinds of uncertainty.

Uncertainties exist when applying future anticipated baselines, including insufficient data or information about a physical or economic process being evaluated, model/data specification, inherent statistical uncertainties, etc. The reference point section discussed limitations related to LULUCF-related data, which are also relevant for future anticipated baselines based on that data. Also, estimation of future BAU or counterfactual scenarios for LULUCF is often more challenging than such efforts with other sectors (e.g., energy) because it involves generating future projections of the many complex natural systems, anthropogenic activities, and related carbon stocks and fluxes. The development of the future anticipated BAU baseline and counterfactual scenarios require simulations or projections of future biophysical, policy, and economic conditions, which often rely on the best available information and expectations to inform model parameters and assumptions. Model parameters and assumptions about future or counterfactual economic, policy,

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[46] BAU baseline cases could assume that future trends follow those of the past and may or may not involve anticipated policy and/or market changes in the future.

and biophysical conditions play a significant role in resulting estimates of future or counterfactual potential carbon stocks and other impacts from changes in biogenic feedstock demand and use.

In the technical appendices, the framework uses the anticipated baseline in a prospective manner, referred to as the future anticipated baseline, and relies on historical biophysical and economic information as well as expectations of future environmental and biophysical conditions to develop illustrative future BAU baseline and alternative scenarios.. Future anticipated baselines have been broadly applied to evaluate the potential future impacts of specific policies or the marginal impacts of an action, holding everything else constant between future scenarios.[47] This baseline approach allows for evaluation of possible effects of stationary source biogenic feedstock demand changes on the biogenic feedstock production landscape and related net biogenic CO_2 fluxes over time by capturing the complex interactions between biogenic feedstock production and forest product markets, including: biogenic feedstock demand; market-driven changes in planting, management, and harvest regimes; direct land use management or land use change emissions; and possible leakage (market substitution or other indirect land use changes and related GHG implications). This approach also allows for consideration of alternate fates (e.g., what would happen to the feedstock if not combusted for energy) and regional differences as well as behavioral responses to market incentives.

4.1.3. Application of Different Baseline Approaches

This report recognizes that the approach to developing baselines may differ according to the specific application of the framework; therefore, the framework methodology provides flexibility to support both reference point and anticipated baselines and possibly others. Application of this framework in a specific program or policy may involve use of either baseline approach in a retrospective or prospective time frame, some combination of the two, or some other approach.

The choice of which baseline approach to apply necessarily involves tradeoffs, which must be considered by the user of the framework. Also, depending on the application of the framework, choices need to be made about other framework components, such as spatial or temporal scale. Important considerations when determining an appropriate baseline approach include:

- ***Data availability:*** In the absence of adequate observational data that can be used to estimate carbon stock changes between two points in time, the anticipated baseline approach could be used to simulate the change in emissions from increased biomass use.
- ***Model Availability:*** Though both baselines can be limited by data availability, the anticipated baseline also depends on economic models with certain components (discussed in Appendix J). Depending on the feedstock, or the choice of spatial or temporal scale,

[47] In contrast, with a retrospective reference point approach there may have been other factors that changed in the historical period (e.g., economic growth, natural disturbance, new government policy encouraging tree planting) besides a change in biogenic feedstock production for energy use that affect biogenic feedstock carbon levels on the assessment landscape, but the impact of those factors cannot be separated from the impact of bioenergy. This is an important distinction between the retrospective reference point and future anticipated baseline approaches.

necessary models/model components may not exist or be accessible. For instance, using economic models to simulate changes in emissions at a spatially disaggregated level (state or sub-state) may not be possible at the time of assessment and could require new model development specific to the assessment region.

- ***Specific policy or program goals:*** Choice of baseline approach should account for the specific goals of the policy or program. If a program requires an evaluation of the additional impact of a new source of feedstock consumption, then the reference point baseline approach would not be appropriate. However, if programs require an assessment of historic emissions, a reference point approach could be necessary. [48]

To highlight the various issues surrounding baselines and facilitate consideration of each approach at the regional level, the two different baselines are applied to generate illustrative values in the appendices as follows: retrospective reference point analysis of forest- and agriculture-derived feedstocks in Appendices H and I; future anticipated baseline of forest- and agriculture-derived feedstocks in Appendices K and L[49]; Appendix M gives an overall comparison and discussion of different examples presented in appendices from both baseline approaches. For the waste-derived feedstocks analysis in Appendix N, an anticipated baseline (counterfactual) assessment between different alternative fate pathways and related avoided emissions is presented.[50]

4.2. Temporal Scale

Assessing biological phenomena inherently necessitates considerations of time. Although different terrestrial and atmospheric processes unfold over time frames ranging from moments to millennia, policy is typically implemented over time frames not as far ranging. There are different perspectives about how to assess future emissions trajectories (e.g., Dornburg and Marland, 2008; Fargione, 2008; Kendall et al., 2009; Levasseur et al., 2010; Walker et al., 2010; Cherubini et al, 2011; Mitchell et al., 2012; Helin et al., 2013; Miner et al., 2014).

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[48] For example, with the reference point baseline approach applied regionally, it is possible to estimate the change in net carbon stocks between two points in time but not possible to estimate how many additional (or how many fewer) stationary sources are using the biogenic feedstock or the impact per each individual user on the regional landscape. With the future anticipated approach in a regional application, different levels of potential future biogenic feedstock demand from and related landscape results (e.g., net forest carbon fluxes) within a region are estimated and compared against a regional BAU reference scenario. Though estimated future increased demand of biogenic feedstocks from a specific region implicitly reflects the impacts of additional users, this approach also cannot isolate the marginal impacts of each additional feedstock user, unless the model(s) used is detailed and disaggregated enough to allow for such detailed analysis. Disaggregation at the level of SubRegional Timber Supply (SRTS) model (Abt et al., 2009; Prestemon and Abt, 2002), for instance, is intended to capture impacts on individual wood basket regions.

[49] Appendix H presents illustrative biogenic landscape attributes using the retrospective reference point baseline, which are applied in example case studies in Appendix I. Appendix K discusses illustrative future anticipated baseline construction methods based on zero biomass use, constant 2009 levels of biogenic feedstock use, and various Annual Energy Outlook (AEO)-derived scenarios. A subset of these baselines is then compared with simulated alternative future scenarios with increased production and use of biogenic feedstocks for energy and industrial processes at stationary sources in Appendix L.

[50] The analysis for waste-derived feedstocks consists of counterfactual exercise, comparing different practices and alternative fates.

GHG emissions assessment can be sensitive to accounting time frames, emissions flux trajectories, and reporting periods. In some situations, direct emissions of all types, including from biological phenomena, are accounted for over a single year, in terms of tons of emissions per year. For example, in national-scale GHG inventories submitted by Parties to the United Nations Framework Convention on Climate Change (UNFCCC), emissions are estimated and reported for all sectors and Parties over a calendar year (UNFCCC, 2006). The U.S. GHG Reporting Program also has annual emissions reporting requirements (EPA, 2013a).

However, biogenic CO_2 fluxes related to the production and use of some biogenic feedstocks can take place over periods of time longer than a year, or even decades, because of the time needed to grow to a harvestable size (in the case of trees) and the time needed for some landscape effects related to feedstock production to unfold (such as soil carbon pool effects and decay rates). The potential mismatch of temporal scales between direct emissions coming out of the stack when a biogenic feedstock is used and longer term factors, including carbon sequestration via feedstock growth or carbon accumulation in soil, adds to the complexity of biogenic CO_2 assessments. Thus, it may be necessary to distinguish between the "emissions horizon" and the "assessment horizon." The emissions horizon is the period of time during which the biogenic carbon-based fluxes resulting from actions taking place today actually occur, while the assessment horizon is a period of time selected for the analysis of the carbon fluxes. In effect, these time horizons can differ significantly.

When establishing a temporal scale for assessing the biogenic landscape attributes and related biogenic CO_2 fluxes, determinations should include:

- Whether to include all past and/or future estimated biogenic carbon-based emissions related to biogenic feedstock production or the emissions horizon (e.g., from potential avoided decay from feedstock use or long-term impacts on soil carbon stocks);
- Whether to establish a specified time frame over which emissions fluxes are accounted for (which could be shorter or longer than the emissions horizon) or just emissions that occur in the year the biogenic feedstock is used or the accounting horizon; and
- Whether future emissions and/or sequestration should be valued the same as emissions occurring today or whether future emissions should be discounted over time.

4.2.1. Implications of Different Temporal Scales

The selection of temporal scale could affect the results of any analysis evaluating biogenic CO_2 fluxes associated with biogenic feedstock production. Considerations related to the choice of temporal scale can differ with feedstock type and geographic location (e.g., growth rates of different tree species in different locations). Also, determining the temporal scale for assessing biogenic CO_2 fluxes has implications and tradeoffs related to measurement, reporting, and verification of estimates and the ability to reflect carbon dynamics of feedstock production over time.

In terms of the science, there is no single correct answer for the choice of a timescale for assessment: different timescales allow for evaluation of different questions and contexts. Therefore, the choice of timescale is largely dependent on specific applications of the framework and related needs or preferences for accounting time such as use of discount rates, inclusion of estimated future climate change impacts, radiative forcing, or any other parameters for analysis.

There are important tradeoffs to consider when choosing a temporal scale for assessment, especially in the context of a prospective analysis, when considering feedstocks with long rotations, and in applications where past biogenic CO_2 fluxes and activities may be included. The following factors should be taken into account to help determine the most appropriate temporal scale:

- ***Feedstock choice:*** Different feedstocks have different growth and harvest intervals, so the choice of temporal scale could vary depending on what feedstock type is being evaluated. For example, if the feedstock is an annual crop with a one-year growing cycle (e.g., corn stover), a shorter time frame could be sufficient. However, for forest-derived biomass, a longer-term assessment would likely be necessary to capture emissions changes over full growth and harvest cycles (which can range from 20 to 80 years for managed forest systems in the United States).
- ***Region:*** Biophysical landscape attributes vary from region to region, so depending on where the assessment takes place, a longer temporal scale might be necessary. For example, setting an assessment time scale nationally for the United States for roundwood might not be appropriate, because the growth and harvest intervals for short-rotation tree species in the Southeastern U.S. are much different than managed forest systems elsewhere in the U.S. Setting a temporal scale that is too short could cause an assessment to miss decades of tree growth and harvest cycles and would inaccurately represent investment decisions driving land use and management in the Pacific Northwest. Conversely, very long time frames (e.g., 100+ years) can obscure important shorter term land use activities and related biogenic CO_2 fluxes.
- ***Data Availability:*** Also important is the availability of data and/or models for conducting assessments. For instance, a one-year assessment scale using the retrospective reference point baseline would not be possible if assessment of the feedstock relies on observational data that are compiled only every 5+ years.
- ***Policy or program application:*** Finally, determination of temporal scale should align with the specific goals of the policy or program that the framework is applied to (e.g., baseline time frames for initial assessment or renewal of requirements under existing programs).

4.2.2. Potential Framework Applications of Time

The framework can address the issue of time differently depending on the policy or program application of the framework and the baseline used in that application. The discussion here focuses on addressing time within each of the two baseline approaches described above and used in the technical appendices: the retrospective reference point baseline and future anticipated baseline.

When using a retrospective reference point baseline (comparing two points in time historically), explicit choices need to be made about (1) the range of historical years included in the accounting period (e.g., will the time between reference points be 5, 10, 20 years?) and (2) at what point in time to start the analysis. The answer to either or both of these questions could be based in part on data availability. For example, because of different data collection methods, some parts of the country may have more historical and/or more recent forestry data than others. It may be useful to establish specific beginning and/or end points of the analysis period to ensure the analysis uses a time frame where data for all parts of the country are available. In the illustrative applications in the technical appendices, the retrospective reference point baseline approach for calculating biogenic landscape attributes evaluates historical data from the last 5- or 10-year period of available data where possible (Appendix H).

When an assessment is conducted using a future anticipated baseline, integrating time into the assessment of forward-looking phenomena is inherent in the approach, but decisions about how to do so could affect the outcomes (as discussed in the previous subsection). The future anticipated baseline approach offers more flexibility in terms of what temporal scale could be used, but choices of temporal scale can in turn affect outcomes. Therefore, determining the appropriate analysis temporal scale for the future anticipated baseline approach will largely depend on the needs and goals of the assessment. For example, an assessment that primarily focuses on feedstocks that have a one-year growing cycle may find that a shorter assessment time frame would be more appropriate compared with an assessment that focuses on forest-derived feedstocks, where the harvest cycles and landscape carbon effects occur over much longer time frames.

The technical appendix on temporal scale (Appendix B) discusses several approaches for assessing multiyear carbon-based fluxes into the future: (1) front-loading;[51] (2) year-to-year carryover;[52] and (3) annualized carryover.[53] For illustrative purposes in the technical appendices, the future anticipated baseline approach uses a 50-year simulation horizon into the future using a year-to-year carryover construct (as reflected in Appendices L and M). This temporal scale is long enough to capture carbon dynamics of longer rotation feedstock species and short enough to detect significant biogenic CO_2 fluxes related to biogenic feedstock production. The year-to-year carryover approach and time frames used can offer insights about the potential future impacts of biogenic feedstock production and use per the case study assumptions; they were chosen for use in this report for illustrative purposes only and are not meant to be prescriptive.

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[51] The front-loading approach accounts for the net biogenic CO_2 fluxes that will occur over the established assessment time frame associated with biogenic feedstock production and use, and then these fluxes are accounted for upfront in the year that the biogenic feedstock is consumed.

[52] In year-to-year carryover accounting, the net biogenic CO_2 fluxes associated with feedstock production and use in the current year are counted as well as any net biogenic CO_2 fluxes that occur on the feedstock production landscape in the current year due to feedstock use in previous years (e.g., decay, soil carbon pools changing to a new equilibrium state) and thus are "carried over."

[53] Annualized carryover is a type of carryover accounting in which the net biogenic CO_2 fluxes associated with biogenic feedstock production and use are added together (as in front- loading) but then divided by a certain number of years to generate an annualized biogenic CO_2 flux value per unit of feedstock. This approach accounts for cumulative emissions over the impact horizon and then divides those emissions equally over the reporting horizon.

4.2.3. Additional Technical Timing Issues

Because of practical limitations related to data availability and to better represent general trends rather than episodic fluctuations, it may be necessary to aggregate data from a multiyear period and to apply this multiyear average to annual fluxes. The frequency of data collection for key inputs such as carbon sequestration occurring on the landscape may not be annual, and/or annual data may not be publicly available. For example, the Forest Inventory and Analysis (FIA) dataset collected by the USDA Forest Service is updated using methods that reflect full U.S. coverage every 5 to 10 years. Depending on the type and location of the measurement, the carbon pool being measured, and the availability of annual data, it may be more practical to use an average value representing the mean over a period of years rather than an annual value.

Biogenic CO_2 emissions and carbon sequestration levels may also vary from year to year due to weather, other natural or anthropogenic disturbances, or market conditions (e.g., demand) such that even if annual data were available, a single year's value is not likely to represent the overall trends in biogenic carbon stocks and CO_2 fluxes. Therefore, even if data are available for finer temporal scales, it may still be appropriate to apply a multiyear average. Even with multiyear averaging, there may be implications for overall results related to patterns and trends in the observed data.[54] Because different biomass feedstocks have different growth cycles and turnover times, it may also be appropriate to average over different time periods for different feedstocks, depending on temporal characteristics of the feedstock.

If a multiyear integration is applied to biogenic CO_2 flux assessment, then it must be decided when in time the assessment period actually starts: before or after land is converted, at planting, at harvest, or some point in between. The importance of this decision when the assessment period starts largely depends on the scale of the framework application. The choice of when to start an assessment period matters substantially at smaller scales, whereas assessments at larger scales are less sensitive to this aspect of timing because effects may be lost due to other activities affecting biogenic CO_2 fluxes over the larger landscape. In the case of forest feedstocks at a small assessment scale, for example, assessment could start at any point in a standard harvest rotation.

No matter when the assessment begins, the total carbon accumulation over the lifetime of the forest might be the same, but if the time frame chosen does not correspond to exactly one full harvest rotation, then the starting point can impact results. Selecting the point of harvest as the starting point for assessment, especially in conjunction with a short assessment time frame, might overestimate the emissions associated with the production and use of the forest feedstock. If assessment starts at planting when rapid carbon sequestration occurs, again in conjunction with a short time frame (less than one rotation), then an underestimate of the net biogenic CO_2 emissions associated with production and use of the forest feedstock is more likely. Other timing

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[54] For example, a one-time land use conversion from one practice to another (e.g., when forested land is harvested and converted to agricultural crop production instead of being reforested) results in a large emissions pulse in 1 year but is then followed by a few years of low sequestration. If an annual average is calculated over this short time period (starting with the harvest), the result may show higher average emissions than if the average was taken over a longer period of time.

considerations include assumptions about length of feedstock use for bioenergy, ongoing use or one-time flux, and assumptions about other markets over time that may need to be considered in applying the future anticipated baseline approach.

4.3. Spatial Scale

Depending on the policy application, the selection of spatial scale could affect the results of any analysis evaluating GHG emissions and sequestration (Galik and Abt, 2012). The following factors should be taken into account when considering the choice of spatial scale:

- ***Feedstock Characteristics:*** Different feedstocks will have different availability, yields, and production practices.
- ***Landscape Characteristics:*** Differences in physical attributes of the landscape and carbon dynamics.
- ***Statistical Precision and Uncertainty:*** Statistical sampling and data accuracy vary across different spatial scales.
- ***Indirect Effects:*** The amount of leakage in an assessment varies across different spatial scales.

The considerations related to spatial scale listed above can also differ with feedstock type and geographic location (e.g., variations in feedstock characteristics across different locations). Determining the spatial scale for an assessment framework has implications related to measurement, precision of estimates, data reporting and verification, the ability to reflect carbon dynamics in the feedstock production area, and cross-boundary exchanges of biogenic feedstocks. The choice of spatial scale can be greatly influenced by the availability and accuracy of data and the precision with which one can measure and/or model feedstock production as well as market dynamics. The characteristics of the land base—including ownership type and resulting management regime,[55] as well as biophysical characteristics such as species and soil types, climatic conditions, and water availability—are another important consideration when evaluating the choice of spatial scale.

The spatial scale for assessment could occur along a continuum from site specific to global, and there are tradeoffs related to accounting at different points along this continuum. For example, the level of data accuracy varies with choice of spatial scale. When carbon stocks are estimated at a larger spatial scale (e.g., global, national, regional) through statistical sampling, the increase in sample size provides more precision (i.e., smaller sampling errors), though resolution on incremental impacts of increased biomass demand can be lost. Global scale may be necessary in some cases to do a qualitative or quantitative assessment on potential leakage, such as indirect land-use effects in other countries. National scale could be appropriate for feedstocks for which there is little or no variety in production and consumption patterns (e.g., waste-derived, some

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[55] 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). As these lands are currently managed, 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).

industrial by-products). Moving from a larger scale to a smaller scale increases the ability to account for differences in feedstock species, production site environmental conditions, and local market factors. However, moving to a smaller assessment scale may ignore potential leakage effects. For smaller scales, the estimates tend to be less reliable due to a lack of statistical power associated with small sample size (Westfall et al., 2013). Estimates at smaller scales could be derived from other sources such as special inventories or surveys (i.e., thorough inventories conducted as part of a forest management plan). Assessment at this scale does allow for evaluation of incremental impacts of increased biomass demand on specific sites.

In terms of the science, there is no single correct answer for the choice of a spatial scale for assessment: different spatial scales allow for evaluation of different questions and contexts. Therefore, the choice of spatial scale is largely dependent on specific applications of the framework and related needs or preferences, considering the implications of feedstock and landscape characteristics, statistical precision and uncertainty, indirect effects, or any other parameters. This report evaluates the implications of different spatial choices and for illustrative purposes uses a landscape (regional) scale to generate example biogenic assessment factor calculations. The technical issues one would need to consider to make an appropriate choice of spatial scale are discussed briefly below and are considered in more detail in Appendix C.

4.3.1. Smaller Spatial Scales

The finest level of resolution (aside from a single tree) is the stand or field level. Assessments at the stand or field level can allow for a direct linkage between the biogenic CO_2 fluxes occurring on the landscape and the stationary source. This small scale of assessment could capture management practices as well as direct land use changes, including evaluation of what alternative or previous land uses might have been. For example, the cultivation of the same feedstock could have different landscape effects if grown on fallow land versus replacing existing crops. Choice of a small assessment scale might be appropriate for a policy or program application assessing biogenic CO_2 emissions from a relatively closed stationary source production system; that is, a stationary source that relies on a single feedstock sourced from a single production area and that has limited impact on aggregate markets.

However, such a small assessment scale cannot take into account potential broader market impacts captured with larger regions. For instance, biogenic feedstock production and related carbon stocks within the evaluated area might be increasing, but this increase could have market ramifications that in turn cause shifts in production of the feedstock or other commodities outside the assessment area. Also, assessments at smaller scales can be challenging because data would need to be collected and/or modeled for each feedstock production site from which a stationary source procures feedstocks and sites might need to be monitored for long periods of time (e.g., in cases of long rotation periods such as in Pacific Northwest forests). If the precise location of feedstock production is not known, one might still be able to generalize a fuelshed into a region encompassing local and likely sources.[56] Fuelsheds can be shared by nearby facilities, and they may change over time as supply and market dynamics change (e.g., demand, product substitution).

With the data collected when the feedstock is received at a stationary source, it may be possible to determine the precise location of the feedstock production site, or it may only be possible to know the broad geographic origin. For example, facilities operating primarily on long-term procurement contracts will likely use the same feedstock production sites year after year, and the geographic location of those sites can be known. In such cases, measurement and analysis of production-related biogenic CO_2 fluxes at a localized scale is possible. On the other hand, for stationary sources operating using aggregated feedstocks (e.g., agricultural residues from multiple landowners aggregated at a centralized site) or for feedstocks that require storage and may become mixed (e.g., logging residues), it may be difficult to know precisely the location of feedstock production. In these cases, only the broad geographic region might be identified. Also, for some feedstocks, production sites may vary from year to year (e.g., forestry operations that may not return to the same location for decades after harvest).

By the same token, analysis at a small scale (i.e., stand level) may obscure the impacts of a coherent management (e.g., silvicultural practices such as thinnings[57]) regime on a broader landscape. For example, consider an analysis focused on one stand of timber over a few decades. If the assessment starts at point of harvest, then over the course of the analyses the carbon stocks may return to their original levels but only if the stand regrows and sequesters an equivalent amount of carbon as when it was first harvested. Using a stand-level assessment approach in this example, the production and use of the biogenic feedstock yields considerable biogenic CO_2 emissions in the short term (due to the harvest), with no net emissions in the long term. On the other hand, consider a timber fuelshed with multiple, multi-aged stands: at any given point in time, some stands are harvested while others are growing. At the fuelshed scale, a carbon balance over the full suite of stands may be achieved in the short term if harvests account for less carbon than the increase in carbon in fuelshed feedstock biomass. Furthermore, if the sampling effort is insufficient for

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[56] For example, several analyses have used a circular fuelshed with a straight-line or road-distance radius as an approximation for forest-related feedstocks (50 miles straight line, Galik and Abt, 2012; 30 miles road distance, Brinkman and Munsell, 2012).

[57] Thinnings as a silvicultural management strategy has been practiced in the U.S. for some time (e.g., Smith et al., 1997), and is commonplace in even-aged managed forest stocks, particularly in regions like the Southeast U.S., where "pre-commercial" and "commercial" thinnings are used as a stock improvement strategy and in some cases an income generation strategy (e.g., the sale of biomass or fuelwood may also help to offset cost of pre-commercial work). Some studies have evaluated the potential for and practices for thinning and thinned materials to supply bioenergy markets (e.g., Manley & Richardson, 1995; Egnell & Björheden, 2013). Other works note that the "widespread" practice of thinning to reduce potential fuels for wildfire, particularly in the western U.S., and reduce the amount of carbon emissions potentially released through wildfire (e.g., Evans & Finkral, 2009). Literature suggested that increased demand for bioenergy could alter forest management, possibly resulting increased harvest/use of low-quality wood material, such as materials from commercial or pre-commercial thinnings or small roundwood. These potential shifts have in turn increased attention to the role of harvest guidelines and best practice systems to guide bioenergy-related forest management decisions (e.g., Kittler, et al., 2012; Lattimore et al., 2009). For more discussions and different perspectives on thinnings, also see Biomass Energy Resource Center, 2012; Kerr and Haufe, 2011; Miner et al, 2014;

adequate coverage of small land areas, then the sample size for the area of interest will be small, resulting in low statistical power and an inconclusive assessment of carbon stocks and fluxes.

4.3.2. Larger Spatial Scales

Existing data can be readily aggregated and presented at larger scales such as states, regions, and nationally. For example, states and the federal government have existing data collection systems relevant to tracking landscape-scale biogenic carbon cycling, such as forest inventories, land surveys, and tax records. However, certain small states (e.g., Rhode Island) may not be large enough (given the current sampling effort or plot density) to offer adequate or accurate data on forest growth and removals, because the associated sampling errors may be too large. States may also implement policies and regulations focusing on forests and agricultural lands, such that all land in a given state may share some basic market and regulatory influences. State-level assessments could become complicated, however, if feedstocks are bought and sold across state boundaries where laws differ from one another (in terms of actual measurements and accounting).[58]

The next spatial scale larger than a state level could be geographic regions, which may include multiple states. Regions may be large enough that data on carbon stocks and land use change are largely available and (assuming sampling is adequate) less subject to error from small sample sizes. Depending on how they are defined, regions may be small enough to capture principal differences in biophysical characteristics, such as temperature and species types in different regions across the United States. For forest feedstocks, for example, regions could be defined on the basis of relative homogeneity of characteristics such as forest types, growth rates, and climate. Also, determining a regional scale might include considerations related to market characteristics, with multistate regions forming coherent markets for biogenic feedstocks[59] and the ability of regions to capture market effects. Regional boundaries must be drawn carefully to ensure the region is large enough to offer adequate data accuracy and availability, yet small enough to reflect carbon dynamics and meaningfully link to the "drivers of change," (i.e., the actions of feedstock users, to landscape carbon stock changes). One potential difficulty with assessments at the regional spatial scale is that each region may encompass multiple states and political boundaries. Also at regional scales, there is less resolution on the incremental impact of increased biogenic feedstock demand from specific entities and/or on specific sites than assessments on smaller scales.

With larger spatial scales like regional or national scales, it is possible that smaller-scale trends in carbon stocks could be masked, since carbon stocks could be declining in some areas and increasing

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[58] One difficulty with defining spatial scale with a political boundary is accounting for biogenic feedstock transfers across boundaries. For example, wood-using mills in one state often purchase and transport wood across state boundaries (Teeter et al., 2006). This adds accounting complexity because biogenic CO_2 fluxes from feedstock production may occur in a different region than biogenic CO_2 fluxes from feedstock use.

[59] An example of a fixed regional framework is the EPA Emissions & Generation Resource Integrated Database (eGRID) region structure. eGRID is used for calculating GHG emissions related to electricity generation. Subregions nest within regions defined by the North American Electric Reliability Corporation (NERC). Regions vary widely in size, from small portions of an individual state to areas encompassing portions of seven large states. For more information on NERC and eGRID regions, consult www.epa.gov/egrid.

in others.[60] For example, if one region has a declining carbon stock while another region has a slightly higher level of increasing stock, a national-scale analysis that averaged across all regions could indicate that feedstock carbon overall is increasing and could possibly encourage more feedstock removal including from the region with declining stock, which could be problematic depending on the goals of the policy being implemented. Using the same scenario and applying a regional scale illustrates potential market effects of scale: if an assessment indicates that feedstocks from one region have increasing stock and thus could receive a more desirable assessment factor, this outcome could possibly shift demand to that region (if all else is equal, such as policies, tax structures, etc.).

Similarly, a national scale for agricultural biogenic feedstock production might also mask regional and local differences in length of the growing season, yield per acre, above- and belowground 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). On the other hand, national-level assessments can give high-level insights concerning biogenic CO_2 fluxes from forests and agricultural landscapes and biogenic feedstock market interactions. Lastly, if assessments take place at the national scale, then domestic indirect land use change and related emissions leakage between subnational regions or states would be implicitly captured (more discussion on leakage in Section 4.5 and in Appendix E).

Some waste-derived feedstock materials, such as MSW, may have some regional variability, including the composition of waste (which can vary from community to community within a region) and regional climate factors that affect methane (CH_4) oxidation via cover soils at managed landfills (Bogner et al., 2007; EPA, 2009; Spokas and Bogner, 2011). However, there is a lack of literature describing the degree to which composition of MSW can vary from region to region. Although composition of MSW may vary regionally, this mainly contributes to potential generation amounts of CO_2 and CH_4 in a given landfill, whereas the framework methodology for waste-derived feedstocks focuses on how the CO_2 and CH_4 from MSW is treated when used in one activity versus another. As a result, CO_2 and CH_4 from MSW could be treated similarly across the U.S., i.e., differences would be based on the amount of waste generated, not on variation in the composition).

4.3.3. International Considerations

The pricing and flow of biogenic feedstocks and related commodities globally have the potential to significantly affect domestic demand and supply dynamics and could thus affect U.S. and international feedstock and related commodity production sites and related biogenic CO_2 fluxes. For example, recently increasing pellet demand related to renewable energy policies in the European Union is significantly influencing land use and production activities in the Southeastern United States (Spelter, 2009; Cocchi, 2011; NREL, 2013). Conversely, international feedstock

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[60] At larger scales, changes in carbon stocks could be more heavily influenced by a variety of factors in addition to biogenic feedstock use for energy, including natural (e.g., hurricanes, pest, fire) and anthropogenic (e.g., development, park designations) drivers.

production and potential feedstock imports to the United States could affect the domestic biogenic feedstock market and related land use activities and biogenic CO_2 fluxes (EIA, 2012).

Also, increases in U.S. biogenic feedstock production could affect traditional commodity markets and potentially trigger leakage effects internationally. For example, if biogenic feedstock demand causes domestic land use to shift in biogenic feedstock production, the demand for the displaced crops could be made up by converting lands abroad into cultivation to meet that demand. A global analysis of changes in feedstock demand and related commodity market and land use activities could estimate the potential directionality and magnitude of these effects.

The framework is scalable and can be applied at various spatial scales, from a small scale (plot/entity-level) to global. For example, at the global level, it could be used to assess internationally produced feedstock trade flows, depending on policy requirements and/or international agreements related to GHG emissions assessments. However, for some U.S. domestic policy analyses (e.g., certain waste-derived feedstocks), application of the framework on a global scale may not be required. The illustrative assessment factor calculations presented in the technical appendices of this report are conducted on a domestic regional scale and do not evaluate treatments for exports and imports of international feedstocks or include a global scale assessment.

4.3.4. Spatial Scale Used in the Illustrative Applications in the Technical Appendices

The examples presented in the technical appendices use a regional spatial scale[61] (although, as discussed above, the methodology is scalable). At a regional scale, land areas are large enough that accurate data are available to represent trends in carbon stocks and land use change, but the regional scale is small enough that key differences in regional biophysical characteristics, such as growth and decomposition rates, as well as dynamics of regional feedstock markets, are captured (see Appendix C for additional technical details on spatial scale considerations and Appendices H through M for the illustrative case studies discussions).

4.4. Relationship between Spatial and Temporal Scales

Broadly speaking, the balance between carbon sequestration and carbon emitted on a given landscape can be estimated by measuring the change in the carbon stocks in biologic material over a given period of time (using a reference point baseline approach) or by comparing relative estimated volumes along different projection scenarios (using an anticipated baseline approach). For annual agricultural crops, for example, this calculation for the feedstock itself (aside from non-feedstock biogenic CO_2 fluxes from, for example, soil carbon or land use change effects) can be fairly straightforward; typically at any scale, the amount of biogenic feedstock harvested and used during one year may be fully replaced by feedstock growth during the same year.

However, when considering biogenic feedstocks with rotation ages longer than one year (such as a forest or some dedicated bioenergy crops such as switchgrass) or in cases where biogenic feedstock

[61] The SAB Biogenic Carbon Panel recommended that EPA consider regional-level assessment factor values (SAB, 2012) but did not suggest specific regions.

production has longer term landscape effects (such as changes in soil carbon pool equilibrium or in volumes of materials that decay), the scales of time and space can begin to interact, adding complexity to any assessment of biogenic feedstock production activities and related biogenic CO_2 fluxes. Hypothetically, if one hectare of forest is harvested and combusted, measurement of the tree biomass at the beginning and end of the year will show a net release of biogenic CO_2 to the atmosphere, because combustion emissions exceeded carbon uptake during growth on that hectare for that year. If, however, one measures the mass of trees on that hectare at the beginning and end of a longer period, for example, a 60-year period (assuming this is longer than the rotation age of the forest species and thus includes at least one harvest), this may show that over time the mass of trees—and thus carbon stock—on that hectare is unchanged. In this example, using the longer time frame for integration shows that harvest and combustion (emissions) are eventually equivalent to growth (sequestration).

The following hypothetical example illustrates that the same result can occur with a short time period and larger spatial scale. If 59 hectares of forest are growing uninterrupted alongside the 1 hectare that is harvested and reestablished during 1 year, the total mass of forest in the full 60 hectares is largely the same at the beginning and end of the year. This is because the carbon emitted from harvesting the 1 hectare has been counterbalanced by growth in the remaining 59 hectares and new seedlings on the harvested area. In this case, then, overall equivalence is established for a single year in the 60-hectare parcel.[62]

The simple examples above illustrate the complex interplay between spatial and temporal scales when assessing biogenic CO_2 fluxes. Although integration over time and integration over space are very similar, they are not identical. Both cases above demonstrate that returning to the preexisting carbon stock in the biosphere is not the same as returning to the circumstance that would have prevailed had there been no harvest, because emissions and sequestration have both occurred in the meantime (not only in regard to the feedstock itself, but to the landscape on which it is grown, for example, soil carbon). Integration, or lack of integration, over time confronts the additional issue of whether there is a time-dependent "value" of carbon: do current emissions have the same value as future emissions? In other words, does carbon sequestration occurring over the next 60 years compensate for carbon emitted to the atmosphere today? Can carbon sequestration occurring over the prior 60 years be "banked" to counterbalance the carbon emitted today? This framework does not specifically propose or restrict the use of time values for evaluation, because various time values may be desired in specific policy or program applications (see Appendix B for further detail on temporal scale issues, including a discussion on the valuation of time and discounting).

Ultimately, carbon stocks or flows that have high variability at fine spatial or temporal scales may have much less variability when averaged over larger areas or longer temporal scales. Integrating over long temporal scales may reduce the variability observed at small spatial scales, and integrating over large areas may reduce the variability observed over small temporal scales.

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[62] These are hypothetical examples that are not meant to be representative of typical conditions in the United States (i.e., annual growth on 59 ha equals standing biomass harvested on 1 ha or a 60-year rotation period is not typical for all U.S. regions).

However, it is not safe to assume that integrating over large areas and long time frames is always the best option. Large spatial scales and long temporal scales are not necessarily the most accurate way to conduct specific policy/program assessments because the combination of the two may not offer the level of detail needed (e.g., biophysical differences in species/landscapes, shorter time frames and/or subregional analysis needed for policy analysis) and may mask important smaller-scale impacts. In essence, averaging over space may yield the same numeric result as averaging over time, but the implications can be quite different, as illustrated above.

4.5. Leakage

This framework relies on the IPCC definition of "leakage," which is defined as the indirect impacts of a targeted activity in a certain place at a certain time on carbon storage at another place or time (IPCC, 2000). In the context of biogenic CO_2 fluxes, leakage represents any biogenic CO_2 flux impacts outside of a biogenic feedstock production assessment scope that can be attributed to the production activities (e.g., replacement of diverted crop, livestock, or forest products on other lands due to a change in land use from conventional products to biogenic feedstocks). Leakage is an externality common to many policies and occurs in many different contexts (e.g., benefits of local tourism extending beyond the region or technological innovation spreading from one firm to several others). Leakage, both positive and negative[63] and depending on the nature and magnitude of the market shifts, could have biogenic CO_2 flux effects that range from fairly minimal to quite large.

One of the primary drivers of leakage is economics, including market interactions that can result in changes in production as well as land use activities. Increased demand for biogenic feedstocks might cause higher prices for those feedstocks, which in turn might trigger more production of biomass feedstocks. These increases in production can lead to a succession of land use changes, including the possible conversion of previously forested land or other high-carbon ecosystems to lower carbon systems and the release of carbon stored in soils and vegetation. In globally integrated markets, increased demand for biogenic feedstocks within the assessment area may lead to increased feedstock (or feedstock substitute) production outside the assessment boundaries. Thus, associated emissions may shift from assessed regions to unassessed regions. If leakage leads to biogenic CO_2 fluxes outside the assessment area, then not accounting for it could bias the results toward lower or higher overall emission impacts (lower if leakage is negative, higher if leakage is positive).

One form of leakage, indirect land use change, may occur in an unplanned and unanticipated manner. Detecting leakage resulting from land use change outside an assessment boundary is complex and involves considering multiple variables, including connectedness of output and land markets, mobility of labor and capital, consumer flexibility, producer flexibility, availability of

[63] Negative leakage indicates net emissions generated outside the assessment scope due to changed feedstock production within the assessment scope. Positive leakage indicates net sequestration generated outside the assessment scope due to changed feedstock production within the assessment scope.

alternative lands for production, and the ability of producers to change their emissions profile without modifying production (Henders and Ostwald, 2012; Wunder, 2008).

Determining the value of these numerous variables is difficult, and the literature offers a disparate picture of leakage magnitude (Kim and Dale, 2011; Murray, 2008). Several different leakage measurement strategies have been used in the literature, but these strategies show large variations in the type and quality of data required and the estimates they provide.

Although leakage is difficult to determine, in some circumstances it may be a significant factor in determining net biogenic CO_2 fluxes. The framework, therefore, can accommodate calculations of leakage effects; however, the framework does not choose or develop a specific methodology for identifying and evaluating these effects. If an application of this framework requires leakage analysis, the method chosen for such an analysis should reflect the needs/parameters of the specific policy or program context. Within the context of the Clean Air Act, not all regulatory actions explicitly require a leakage assessment. However, one example of a specific policy application that includes leakage analysis is the Renewable Fuel Standard (RFS). The RFS took into account indirect effects of biofuel production and use, including international leakage effects such as indirect land use change and related GHG emissions.[64] Appendix E provides more information on a variety of leakage estimates in the literature.

4.6. Feedstock Categorization

The delineation of different feedstock categories allows for groupings of feedstocks that share similar attributes for the purpose of assessment within this framework. These attributes include:

- Feedstocks with similar biogenic landscape attributes (e.g., feedstock turnover time);
- Feedstocks with similar temporal characteristics;
- Feedstocks with similar management techniques;
- Feedstocks with similar process attributes (e.g., combustion process types); and
- Feedstocks with similar market or alternative uses.

The scientific literature on biogenic feedstock classification systems is limited and varies, with categorizations designed to be most useful within a particular study or presentation. As a result, a new categorization system is developed and used in this framework. When approaching feedstock categorization, a few key considerations should be taken into account: these considerations are outlined below, followed by presentation of the feedstock categorization used in the framework. Details on various feedstock classification systems found in the literature for other purposes can be found in Appendix D.

[64] For more information on the Renewable Fuel Standard, please see the RFS Regulatory Impact Analysis (EPA, 2010).

4.6.1. Temporal Scale and Feedstock Categorization

One consideration when classifying biogenic feedstocks is the inherently different turnover times (i.e., growth cycles and management regimes) of different biogenic feedstocks. In most cases, feedstocks with similar growth and harvest characteristics can be given the same treatment or considerations in the framework. For example, for materials typically harvested and replenished within one year, such as many conventional agricultural crops or residues, there may be no change in the net biogenic CO_2 contribution to the atmosphere from the growth and harvest of the feedstock itself. However, there may be changes in the overall production site non-feedstock carbon pools (i.e., contained in agricultural soils, detrital pools, or elsewhere in the landscape as a result of the feedstock management and/or harvest) that should be considered. For feedstocks with longer turnover times, such as those derived from forests, the relative rates of feedstock harvest and replenishment are related to the spatial and temporal scales considered, as discussed in previous sections.

For feedstocks that, if not used as a biogenic feedstock and left on the landscape, would decompose over long periods of time, such as logging residues, it is important to acknowledge the pattern of decomposition over time if possible. If left onsite, logging residues can decay and release CO_2 to the atmosphere and soils naturally over periods ranging from years to decades, depending on biophysical characteristics and forest management practices. Harvest and combustion of these residues, on the other hand, converts the residue material to CO_2 in a very short time.

4.6.2. Spatial Scale and Feedstock Categorization

For forest-derived and agriculture-derived feedstocks, there also are distinct differences in species type, feedstock growth, decomposition, and climate and ecosystem characteristics in different parts of the United States. Disaggregating feedstock categories into subcategories could allow for analysis of feedstock differences per different geographic production locations. Assessing feedstocks by landscape or regional characteristics can allow for evaluation of biophysical and economic patterns in growth and decay by region, as well as for regionally specific calculation of the emissions and sequestration associated with feedstock production.

4.6.3. Feedstock Categorization Used in the Framework

The feedstock classification system used here applies three broad feedstock categories: forest-derived, agriculture-derived, and waste-derived feedstocks. These feedstocks are further subdivided into subcategories, as follows (see Appendix D for details):

Forest-derived feedstocks:

- Roundwood
- Logging residues
- Industrial processing by-products, which includes two subcategories:
  - Those with no current alternative market uses such as pulping liquor
  - Those with current alternative market uses, such as wood mill residues (e.g., chips, bark, and sawdust)

Agriculture-derived feedstocks:

- Conventional agricultural crops
- Crop residues
- Dedicated energy crops, such as:
  - Short-rotation woody crops
  - Switchgrass
- Industrial processing by-products, which includes two subcategories:
  - Those with no current alternative market uses such as shells, husks, and cobs
  - Those with current alternative market uses, such as animal fats, oils, and greases, distillers grains

Waste-derived feedstocks:

- Municipal solid waste, including food waste
- Animal waste/litter
- Wastewater

The framework could also be used to consider secondary use feedstocks. Secondary use feedstocks are biogenic materials that exit a particular stationary source (i.e., primary stationary source) or the stationary source supply chain where the original biogenic feedstock material is transformed into a product or by-product and are then used for energy production at a different stationary source (i.e., secondary stationary source). For example, suppose a secondary stationary source uses for energy an agriculture- or forest-derived industrial processing by-product such as distillers' grains or woody slabs or residuals from a primary stationary source. If necessary, the landscape attributes from the original biogenic feedstock at the primary source could be used at the secondary entity. Hypothetically, the same treatment could be used in the case of energy products such as pellets or ethanol used for energy at a secondary stationary source.

For purposes of this report, biogenic feedstocks have been classified broadly into the feedstock categories identified above based on the physical and other attributes those feedstocks possess. This categorization does not represent a formal or legal definition, nor does it intend to replace any existing legal definitions. The framework is designed to be flexible so it can be modified as needed to be applicable to nearly all domestic biogenic feedstocks currently in use or under consideration for bioenergy production. However, new and unconventional, or otherwise unanticipated, feedstocks may emerge over time and may fit under the categories above or may necessitate new categories.

5. Discussion

This report presents a methodological framework for assessing the extent to which the production, processing, and use of biogenic material at stationary sources results in a net atmospheric contribution of biogenic CO_2 emissions. It is a revision of EPA's original September 2011 *Draft Accounting Framework for Biogenic CO_2 Emissions from Stationary Sources* and is responsive to a peer review of that draft report conducted by the Biogenic Carbon Emissions Panel of EPA's Science Advisory Board (SAB Panel).

The revised framework is an analytical tool designed for many users, including facilities and companies that produce biogenic feedstocks and/or use biogenic feedstocks in energy production at stationary sources, and policymakers considering different GHG-related policies and programs. Users of this framework can review the biogenic assessment factor (*BAF*) equation presented in Part 2; consider the different possible approaches—representative, customized, or hybrid—presented in Part 3; and examine in Part 4 the key decisions for a user to make to inform the biogenic emissions assessment, including choice of baseline, temporal scale, feedstock categories, and spatial scale. Illustrative applications of the framework are included in in the technical appendices.

The discussion of the scientific elements associated with biogenic CO_2 fluxes and the presentation of the assessment method and illustrative calculations aim to provide a technical foundation for assessing the extent to which the production, processing, and use of biogenic material at stationary sources results in a net atmospheric contribution of biogenic CO_2 emissions. In addition to the key decisions discussed in the report, stakeholders may wish to consider additional factors when making this type of assessment, including:

- Key policy considerations and associated statutory and regulatory structure of different programs.
- Other complementary policies related to biogenic CO_2 emissions. For example, policies affecting land owners might 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).
- Energy efficiency: Different types of stationary sources (e.g., combined heat and power) use biomass with varying degrees of efficiency (e.g., tons of feedstock required per megawatt or British thermal unit), and efficiency may be an important consideration under certain policies and programs.
- Scale/scope of program: Large-scale programs affecting entire industries on an annual basis may require different technical approaches than programs on a smaller scale.
- Timing: Different program applications may require biogenic CO_2 emissions from a stationary source to be evaluated over specific time frames and/or at specific points in time (e.g., on a prospective basis that would apply over the life of the stationary source, annually).

6. Glossary of Terms

Additionality: A criterion for assessing whether an activity has resulted in GHG emission reductions or removals in addition to what would have occurred in its absence.

Anthropogenic: Resulting from or produced by human beings.

Anticipated Baseline: A *baseline* that assesses the estimated net changes of biogenic CO_2 fluxes and/or carbon stocks between two scenarios at the same specified point in time (e.g., the estimated difference between a business-as-usual [BAU] scenario and an alternative counterfactual scenario that includes changes in environmental, economic, and/or policy conditions.

Assessment Framework: A methodology for assessing the net atmospheric contribution of *biogenic CO_2 emissions* from a *stationary source* that combusts or processes *biogenic feedstocks* taking into account factors related to the *biological carbon cycle*. These factors include *biogenic landscape attributes,* including carbon-based stock changes and *fluxes* (including carbon dioxide and methane fluxes) that occur (or are avoided) on the landscape associated with or affected by feedstock production and biogenic *process attributes* related to processing (transporting, storing, processing) and use of a biogenic feedstock at the stationary source, and/or the alternative fate of biogenic materials if not used for bioenergy.

AVOIDEMIT: Landscape attribute term *AVOIDEMIT* accounts for the avoidance of estimated biogenic emissions that could have occurred on the feedstock landscape without biogenic feedstock removal (e.g., avoided decomposition) or per an alternative management strategy (e.g., waste-derived feedstocks).

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. Examples of baselines include an *anticipated baseline* or *reference point baseline*.

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

Bioenergy: Energy derived from *biomass*.

Biogenic Assessment Factor (*BAF*): The *BAF* is a unitless factor that represents the net atmospheric biogenic CO_2 contribution associated with using a *biogenic feedstock* at a *stationary source*, taking into consideration biogenic landscape and process attributes associated with feedstock production, processing, and use at a *stationary source*, relative to the amount of *biogenic feedstock* consumed. This term represents a ratio of the net biogenic *carbon cycle* effects from all stages of growth, harvest/collection, processing, and use of a *biogenic feedstock* (i.e., the *NBE*) relative to the *PGE* of the *biogenic feedstock* consumed for energy (and resulting in stack emissions) at a *stationary source*.

Biogenic Attributes: Attributes associated with *biogenic feedstock* production, such as *sequestration* in the *biogenic feedstock*, avoided *emissions* from residues that would have eventually decomposed onsite if they were not used in the *stationary source*, *emissions* or *sequestration* associated with direct land management or *direct land use change*, and *leakage* (such as indirect *land use change)* associated with biogenic feedstock production.

Biogenic CO_2 Emissions: *Carbon dioxide emissions* related to the natural *carbon cycle* as well as those resulting from the production, harvest, combustion, digestion, fermentation, decomposition, or processing of *biologically based* materials.

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

Biologically based: Non-fossilized and biodegradable organic material originating from modern or contemporarily grown plants, animals, or microorganisms (including products, *by-products*, 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 that is living or dead (e.g., trees, crops, grasses, tree litter, roots), above and belowground and both). 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.

Biosphere: The part of the Earth system comprising all ecosystems and living organisms, in the atmosphere, on land (terrestrial biosphere), or in the oceans (marine biosphere), including derived dead organic matter, such as litter, soil organic matter, and oceanic detritus.

Black Liquor: Industrial paper manufacture involves a procedure known as the Kraft process, where wood is converted into wood pulp and then into paper. The process produces a *by-product* referred to as black liquor (i.e., a liquid mixture of pulping residues [such as lignin and hemicellulose] and inorganic chemicals from the Kraft process [such as sodium hydroxide and sodium sulfide]).

By-product: A material of value produced as a residual of, or incidental to, the conversion process.

Carbon: Chemical element with symbol C and a common atomic weight of 12. 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 Dioxide (CO_2): A naturally occurring gas, which is also produced through anthropogenic activities such as burning *fossil fuels* (such as oil, gas, and coal) from fossil *carbon* deposits, burning *biomass*, *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): The atmospheric impact (*global warming potential [GWP]*) of 1 metric ton of a primary *greenhouse gas* in terms of the equivalent number of metric tons of CO_2 *emissions.* For example, 1 metric ton of *methane (CH_4)* has the same GWP as 25 metric tons of CO_2. Therefore, 1 metric ton CH_4 = 25 metric tons CO_2e.

Carbon Flux: Transfer of *carbon* from one *carbon pool* to another in units of measurement of mass per unit of area and time. The term is used here to encompass both biogenic *carbon dioxide* and *methane*.

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*.

Conversion: Technologies or processes that convert biomass into energy directly, in the form of heat or electricity, or may convert it to another form, such as liquid biofuel or combustible biogas. Examples of biomass conversion processes include biomass-fired or co-fired boilers, biomass gasification or pyrolysis systems, ethanol fermentation processes, and anaerobic digesters.

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

Discounting: A treatment of time approach, in which all of the future net *carbon* flux impacts associated with using the *biogenic feedstock* are given a net present value using a discount rate.

Distiller Grains: Materials 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.

Emissions: Release of *greenhouse gases* and/or their precursors into the atmosphere over a specified area and period of time. A transfer of *carbon* (*flux*) from a *reservoir* to the atmosphere carbon pool. Direct *emissions* are defined at the point in the production process where they are released or transferred and are attributed to that point in the production process (the "point of emission"), whether it is a sector, a technology, or an activity. In the context of an activity, *emissions* may refer to net *emissions* from the entire production process or direct *emissions* from particular points in the production process such as the stack or flue at a *stationary source* or the growth or decomposition of feedstock at the point of harvest or in transit to a stationary source. When applied in the context of a sector, *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.

Feedstock: See *biogenic feedstock*.

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 *fossil fuels*.

Front-loading: A treatment of time approach, which accounts for all of the future net biogenic CO_2 *flux*es associated with the removal of the *biogenic feedstock* are added together and accounted for in the year in which the removed *biogenic feedstock* is consumed at the *stationary source*.

Fuelshed: An aggregate of areas from which feedstock may be drawn for a specific facility.

Global Warming Potential (GWP): An index, based on 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.

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).

GROW: The *GROW* term in the *BAF* equation represents net feedstock growth (or removals) on the feedstock production landscape.

Indirect Land-Use Change: *Land use* change that occurs outside the assessment scope due to changes in *biogenic feedstock* production activities and *land use* within the assessment scope.

L: The process attribute term *L* is a unitless adjustment factor greater than or equal to one that represents *biogenic feedstock* carbon that leaves the supply chain (e.g., via transit or decomposition, deviated for use as a product) between the feedstock production site and input into the conversion process at a *stationary source*. *L* scales *PGE*, as it was measured at the point of assessment, up to account for any losses during transportation or storage between the feedstock production site and the point of assessment. *PGE* times *L* is thus the *carbon* content of the biomass that was grown at the feedstock production site in order to deliver the quantity of feedstock measured at the point of assessment.

Landscape Attributes: *biogenic feedstock carbon* and *carbon*-based fluxes that are associated with the landscape where a *biogenic feedstock* is grown and harvested/collected or avoided emissions from feedstock use.

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 or used (e.g., grazing, timber extraction, residential, commercial, 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.

LEAK: The landscape attribute term *LEAK* accounts for the potential *leakage* associated with *biogenic feedstock* production and use at *stationary sources*.

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.

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 resulting from 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.

LOSS: Represents the actual tons of carbon lost in transportation or storage along the supply chain rather than being emitted during conversion to energy at the *stationary source*.

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.

Methane (CH_4): A hydrocarbon that is a *greenhouse gas* produced through anaerobic (without oxygen) decomposition of waste in landfills, animal digestion, decomposition of animal wastes, production and distribution of natural gas and oil, coal production, and incomplete *fossil fuel* combustion.

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.

Net Biogenic Emissions (*NBE*): The *NBE* term represents the net atmospheric biogenic CO_2 contributions associated with different stages of *biogenic feedstock* production, processing, and use at a *stationary source*. The biogenic landscape attributes (*GROW, AVOIDEMIT, SITETNC,* and *LEAK*, if included) and the biogenic process attributes (*L* and *P*) can be combined with *PGE* to estimate the *NBE* associated with the specific *biogenic feedstock* and stationary source process.

Nitrous Oxide (N_2O): A *greenhouse gas* emitted through soil cultivation practices, especially the use of commercial and organic fertilizers, *fossil fuel* combustion, nitric acid production, and *biomass* burning.

P: The process attribute term *P* is a unitless adjustment factor between zero and one, equal to the share of the carbon content of the feedstock at the point of assessment that is emitted to the atmosphere by a *stationary source* (versus that which is embedded in products). In effect, this term also reflects the share of *carbon* that remains in products, that is either not emitted to the atmosphere or is sold and eventually emitted to the atmosphere by a downstream user.

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.

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

Potential Gross Emissions (*PGE*): Potential gross emissions, represented by *PGE*, is the carbon content of the *biogenic feedstock* used by a specific entity (or generally consumed). This is a quantity that could be measured or estimated at different points of assessment (e.g., at the boiler mouth, *stationary source* gate, feedstock production site, or at the stack: wherever the point of assessment needs to be. Thus, this term can have different values indicated by subscripts, representing different points along the supply chain).

Primary Biogenic Feedstock: *Biogenic feedstock* derived directly from harvested/collected *biomass*, such as acquired directly from the land on which they grew or from a third party that harvested, collected, or aggregated the *biomass*.

Process Attributes: Attributes associated with processing or using *biogenic feedstock*, such as *biogenic carbon* that is embodied in products such as ethanol or biogenic CO_2 fluxes caused by losses that occur during *biogenic feedstock* storage or processing.

PROD: Represents the actual tons of carbon stored in final products or by-products along the supply chain rather than being emitted during conversion to energy at the *stationary source*.

Pyrolysis: *Pyrolysis* is the heating of an organic material, such as *biomass*, in the absence of oxygen. The material is decomposed into combustible gases and *biochar*. Most of these combustible gases can be condensed into a combustible liquid called pyrolysis oil (bio-oil), though there are some permanent gases (CO_2, CO, H_2, light hydrocarbons). *Pyrolysis* of *biomass* thus produces three products: bio-oil, *biochar*, and syngas. The proportion of these products depends on several factors including the composition of the *biogenic feedstock* and process parameters. All things being equal, the yield of bio-oil is optimized under fast pyrolysis conditions (i.e., when the pyrolysis temperature is around 500 °C and the heating rate is high [i.e., 1,000 °C/s]). Processes that use slower heating rates are called slow pyrolysis, and *biochar* is usually the major product of such processes.

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.

Reference Point Baseline: A *baseline* that represents the estimated net change of biogenic CO_2 fluxes and/or *carbon* stocks between two points in time.

Reservoirs: A component of the climate system, other than the atmosphere, that has the capacity to store, accumulate, or release a substance of concern, including *carbon*, a *greenhouse gas*, or a *greenhouse gas* precursor. Oceans, soils, and forests are examples of *reservoirs* of *carbon*. The absolute quantity of the substance of concern held within a *reservoir* at a specified time is called the *carbon stock*.

Roundwood: The portion of tree biomass that would be defined as merchantable (is of sufficient quality for market sale), according to existing forest inventory definitions. This includes trees of commercial species that have good form (e.g., not hollow or "cull") and that are large enough to be harvested and includes the main bole or stem, but not branches or tops.

Scope: Components that could be included as part of the system boundary for an *assessment 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.

SITETNC: The landscape attribute term *SITETNC* accounts for the estimated total net change in non-feedstock carbon pools on the feedstock production site due to *land use* management or *land use* or management changes associated with feedstock production.

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 report, a *stationary source* is any building, facility, structure, or installation that emits or may emit *biogenic CO_2 gases*.

Year-to-year Carryover: A treatment of time approach, which accounts for the *emissions* and/or *sequestration* associated with a unit of *biogenic feedstock* production, harvest, and use in the year in which the *emissions* actually occur.

Working Forest: Those portions of the forest resource within a region that are likely to be used for *biogenic feedstock* production. Excluded from working forests are, for example, protected forest areas, areas not conducive to harvest due to physical conditions (e.g., inoperable soils or steep slopes), regulatory restrictions (e.g., elevation limits in the Northeast), or economic feasibility (e.g., large distance to transportation networks).

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8. Technical Appendices to this Report

The technical appendices to this report contain the detailed background and computations necessary to explain how the methodologies for calculating the various terms in the *BAF* equation were developed to generate the illustrative *BAF* values for sample feedstocks.

Appendix A details the relation of the framework to the IPCC greenhouse gas inventory methods. **Appendices B** through **D** describe the preliminary technical decisions required to implement the framework. Specifically, **Appendix B** provides a theoretical discussion of the key considerations related to the treatment of time in an assessment framework. **Appendix C** discusses spatial scale considerations and explains the implications of choosing different scales, including the regional scale. **Appendix D** describes the categorization of biogenic feedstocks used in this framework.

Appendix E presents a discussion of leakage literature. **Appendix F** provides a general algebraic representation of the biogenic assessment factor equations, which includes detailed examples of how the equation could be adjusted to accommodate different supply chain permutations. **Appendix G** discusses the technical aspects of the biogenic process attributes, equation terms related to use of biogenic feedstock in different stationary source types (*P* and *L*) and provides a discussion of the literature as well as illustrative values for different feedstocks and for sample stationary source applications. **Appendix H** presents a discussion of the illustrative equation terms related to the biogenic landscape attributes of feedstock production and harvest (*GROW, AVOIDEMIT,* and *SITETNC*) for forest- and agriculture-derived feedstocks in the context of the retrospective reference point baseline and provides illustrative calculations of these terms for example feedstock/region combinations. **Appendix I** presents the illustrative *BAF* calculations for the example feedstock/region combinations and example process attribute values for the retrospective reference point baseline.

Appendix J provides a discussion defining what an anticipated baseline is and how it can be applied in different ways, as well as important considerations to apply when choosing a modeling method for applying a future anticipated baseline in the context of assessing biogenic emissions from stationary sources. **Appendix K** describes the methodology used to develop various illustrative future anticipated baselines for use in the following appendix. **Appendix L** presents illustrative applications of the future anticipated baseline approach to specific feedstock/region combinations for forest- and agriculture-derived feedstocks to generate example equation terms and *BAF* calculations. **Appendix M** provides a synopsis of the illustrative *BAF* calculations from the retrospective reference point and future anticipated baseline approaches and sensitivities using both approaches. **Appendix N** describes an evaluation of waste-derived feedstocks, such as municipal solid waste and wastewater treatment.