Appendix J: Anticipated Baselines: Background and Modeling Considerations

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1. Introduction

This appendix describes the anticipated baseline approach and the purpose of, and potential components needed when, applying an anticipated baseline approach prospectively to estimate the land use and biogenic carbon-based emissions and sequestration implications of U.S. biogenic feedstock consumption at stationary sources. Baseline specification can vary in terms of what entity/groups are being analyzed (e.g., industries, economic sectors), time scale, geographic resolution, and, depending on context, environmental issues/attributes (EPA, 2010a).[1] Determination of the most appropriate baseline approach and consequently appropriate modeling approaches and level of detail depends largely on the goals of the assessment.

Establishing a baseline creates a point of comparison necessary for evaluating changes to a system.[2] However, the choice of approach largely depends on the question being asked. Applications of the framework may require a baseline or baselines against which changes of landscape carbon stocks can be measured. Other applications may necessitate a baseline against which the emissions and sequestration associated with the production and use of additional biogenic feedstocks at stationary sources can be estimated and analyzed. Alternative baseline assumptions can yield different results and should be finalized after careful consideration of the specific context in which the framework is applied.

This appendix first highlights what an anticipated baseline is in general and how it compares with other baseline approaches, such as the reference point baseline. The appendix then presents the rationale for using this type of forward-looking approach, followed by a discussion on the rationale for using a prospective, or future, anticipated baseline approach for assessing biogenic emissions at stationary sources. Next is a discussion of data needs, model constructs, and model attributes that should be considered when constructing a future anticipated baseline analysis. The last section briefly describes the model chosen for constructing the baseline and alternative scenarios for the illustrative framework applications of the future anticipated baseline used in this report—the U.S. Forest and Agricultural Sector Model with Greenhouse Gases (FASOM-GHG).

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[1] Guidelines for Preparing Economics Analyses (NCEE), Chapter 5: http://yosemite.epa.gov/ee/epa/eerm.nsf/vwAN/EE-0568-05.pdf/$file/EE-0568-05.pdf

[2] Definitions for baseline vary, including "the reference for measurable quantities from which an alternative outcome can be measured" (IPCC AR4 WGIII) 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 AR4 WGII).

2. Anticipated Baselines: Definitions and Applications

2.1. Definitions and Comparison of Baseline Approaches

Two potential baseline approaches for assessing the biological carbon cycle effects related to biogenic feedstock production and use at stationary sources are evaluated in this appendix. The first baseline approach assesses the estimated net change in carbon between two points in time (i.e., between reference points) (e.g., Fargione et al., 2008; UNFCCC, 2009). This approach allows for estimation of net carbon changes relative to particular points in time. It establishes as the baseline the aggregate carbon stock related to a specific feedstock type on a given land base at a given point in time. It is against this measured reference point that aggregate stocks at another point in time will be compared, and then determines if those aggregate stocks are rising or falling between the two points in time.

In contrast, the second approach, the anticipated baseline, is a comparison between two distinct scenarios, not two points in time. While 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 (i.e., between a business-as-usual [BAU] scenario and an alternative or counterfactual scenario with changes in environmental, economic, and/or policy conditions) (e.g., Searchinger et al., 2009; Sohngen and Sedjo, 2000). This approach uses information regarding carbon stocks and the carbon balance of biogenic feedstock production systems at a certain point in time to determine either the landscape carbon profile related to specific feedstock use at stationary sources or the marginal impact of specific feedstock use at a stationary source. Both of these baseline approaches, reference point and anticipated, can be prospective (e.g., assessing the impact of a particular policy or change in biomass utilization on future carbon stocks) or retrospective (e.g., finding what the impact of an existing policy or biomass utilization has been on carbon stocks).

A primary difference between the two baseline approaches is the ability of the anticipated baseline to evaluate the additional emissions associated with biomass consumption at stationary sources. This “additionality” component is vital to determining the net contribution of additional biogenic feedstock consumption at stationary sources relative to a baseline scenario in which that consumption did not occur (additionality is discusses further in the next section). Another major difference between the reference point and anticipated baseline is the latter’s ability to incorporate potential fundamental changes in a system to gain insights about potential outcomes. In an evolving bioenergy market, such an ability can be useful to test various market and policy conditions. Finally, while a reference point approach can assess what has been taking place on the landscape in terms of emissions fluxes, an anticipated baseline approach provides information about what level of “adjustment” may be appropriate given current and expected future market and production system changes.

One purpose of applying an anticipated baseline is to provide information on potential impacts (positive or negative) of a policy, activity, or other decisions. An anticipated baseline describes the expected “business-as-usual” (BAU) conditions absent a project, policy or other “shock” to a system, against which the potential impacts of a policy or change in markets or other behavior can be described and used to understand the directionality and magnitude of possible impacts.

When anticipated baselines are applied prospectively, they can be used to evaluate scenarios of potential future outcomes relative to an estimated future BAU baseline (e.g., with and without a policy), given a set of assumptions about technologies, markets, and biophysical conditions. It is the difference between these two possible futures that provides insight regarding potential policy impacts. Prospective anticipated baselines are especially important when analysis of existing or recent historical trends to assess potential future conditions or impacts may not be appropriate. For example, it would be inappropriate to construct a retrospective baseline if there is limited or no historical data or experience from which to draw inferences (e.g., national GHG reduction incentives, bioenergy production goals, the use of currently noncommercial technologies such as new agricultural production technologies, or feedstocks not grown at the commercial scale). Use of an anticipated baseline prospectively allows for evaluation of not only future market and policy impacts, but also provides insight into how those impacts deviate from, or are additional to, the BAU trajectory.

Also, an application of a future anticipated baseline approach provides a means to estimate the potential additional emissions and sequestration changes over time in response to changes in biogenic feedstock demand. An assessment over long future time frames is particularly important in the case of the production of long rotation feedstocks such as forest-derived feedstocks as well as in cases of land use or land use management practices that may have long-term effects on landscape fluxes, including deforestation, afforestation to provide woody feedstocks, or fluxes from soil carbon pools.

2.1.1. Additionality

One of the primary purposes for applying an anticipated baseline approach is to ascertain whether an activity or policy has or will have resulted in GHG emission reductions or removals in addition to what would have occurred in the absence of such an action. The difference in net atmospheric carbon dioxide (CO_2) emissions with and without changes in biogenic feedstock use is known as additionality (Murray et al., 2007). Additionality can be determined by assessing the difference in potential net atmospheric CO_2 emissions of a specific level of biogenic feedstock use over a certain period of time (in many cases the BAU baseline) versus the net atmospheric CO_2 emissions that would have occurred over the same time period with a different level of biogenic feedstock use (counterfactual scenario), holding other factors and assumptions consistent between scenarios. When an anticipated BAU baseline consists of no biomass consumption at stationary sources, the counterfactual anticipated scenario allows evaluation of the aggregate, or average, potential market and landscape-level effects of all biogenic feedstock consumption at stationary sources. Similarly, when applied prospectively and compared with a BAU of a specific level of biogenic feedstock usage at stationary sources, an anticipated baseline allows evaluation of the incremental, or marginal, future potential market- and landscape-level effects.

This ability to assess potential additionality is particularly useful in capturing the complex interactions between biogenic feedstock production and forest product markets, including: biogenic feedstock demand; market-driven changes in planting, management, harvest regimes; market substitution effects; and direct land use change and related GHG implications. It also allows for consideration of alternate fates (i.e., what would happen to the feedstock if not combusted for energy), regional differences, and behavioral responses to market incentives. By estimating the impact of a change in policy (or other action) holding all other conditions and assumptions constant, the resulting complex interactions between markets and land use management decisions (e.g., planting regimes, land use) can be attributed to that change in policy (or other action).

2.2. Review of Relevant Literature

There is an extensive body of literature on the potential GHG implications of the expanded use of biogenic feedstocks for energy, many of which use some form of future anticipated baseline for analysis. Most studies have focused on annual, often agricultural, crops as feedstock for bioenergy production, mostly in the context of liquid biofuels (see reviews conducted in Gerber et al., 2008 and Pérez Domínguez and Müller, 2008). A seminal article by Searchinger et al. (2008) questioned the GHG benefits of corn ethanol given the potential for land use change and large increases in GHG emissions as an indirect market response to the biofuel demand stimuli.

More recently, increased attention has been paid to the net GHG consequences of forest bioenergy—either for transportation fuels or for electricity generation (Searchinger et al., 2009; Sedjo and Sohngen, 2012). Researchers have also begun modeling forest bioenergy pathways to better understand the GHG implications of forest bioenergy expansion (Daigneault et al., 2012; Mosnier et al., 2013; Latta et al., 2013). Although this issue mirrors many of the land use and market change concerns of the annual feedstock literature, there are unique challenges in the treatment of feedstocks with long rotations. Evaluation of these feedstocks, such as roundwood, would entail investment dynamics and interactions with traditional forest product markets.

A subset of the agricultural and forest bioenergy literature has applied an intertemporal optimization modeling approach—which explicitly assumes perfect foresight of anticipated future market and policy conditions. Several published manuscripts have applied intertemporal optimization to evaluate the impacts of bioenergy expansion. The Regulatory Impact Analysis of the Renewable Fuel Standard 2 (EPA, 2010b) applied a full suite of models to examine fuel pathway lifecycle analysis of U.S. biofuel expansion, including land use and GHG implications.

Daigneault et al. (2012) analyzed the impacts of forest biomass electricity generation in the United States using a global forest and land use model developed in earlier work and updated to reflect demand for biomass-based energy. Several scenarios were developed to test the sensitivity of results to basic assumptions of land use competition. In cases where conversion of agricultural land to new forest biomass production was unconstrained, carbon stock immediately increased. When land use was constrained, this resulted in a net increase in emissions (decrease in forest carbon stock).

Latta et al. (2013) applied an intertemporal partial equilibrium model of the U.S. forest and agricultural sectors to assess the market, land use, and GHG implications of biomass electricity expansion. Results showed how intertemporal optimization procedures can yield different biomass feedstock portfolios and GHG performance metrics at different points in time. They also evaluated the impacts of restricting feedstock eligibility, land use change, and commodity substitution. The authors highlighted the importance of dynamic considerations and forest and agricultural sector interactions on projecting the GHG effects of biomass electricity expansion in the United States.

Another prominent study is the U.S. Billion-Ton Update (DOE, 2011), which relied on the generation of future biomass supply estimates derived from given price paths for biomass feedstocks. That study estimated forest and agriculture biomass supply (in physical units) and bioenergy supply (in gallons of biofuel and kilowatt-hours [kWh]) at $40, $50, and $60 per dry ton from 2012 to 2030. At $40 and $50 per dry ton, the majority of the biomass supply is derived from agricultural residues and wastes, while at $60 per dry ton bioenergy crops dominate the supply in later years (2022 and 2030).

In the U.S. Energy Information Administration's (EIA's) Annual Energy Outlook (AEO) 2012 projections, biomass energy is one of the fastest growing renewable fuel sources, with expected growth of more than 3% per year until 2035 in the Reference case. The AEO reports both total production of energy from biomass (including wood and wood waste, biomass for liquid fuels, and nonelectric energy demand from wood) and generation in the electric generation and end-use sectors.[3]

There is a currently an expanding pool of research focused specifically on accounting for biogenic emissions, especially in the context of biogenic emissions from forest-related electricity and industrial sector stationary sources. As researchers have not reached agreement regarding the appropriateness of a standard baseline approach, literature addressing this topic will become progressively more available.

2.3. Application of Future Anticipated Baseline Approach in this Report

The goal of prospectively applying an anticipated baseline in this report is to assess the potential future net biogenic CO_2 contributions to the atmosphere from changes in biogenic feedstock consumption for energy generation at stationary sources. This future anticipated baseline approach addresses the question "Is more or less carbon stored in the system over time compared to what would have been stored in the absence of changes in biogenic feedstock use?" Thus, the future anticipated baseline approach requires a means to estimate the potential incremental impact of changes in biogenic feedstock production and use at stationary sources under specific scenario assumptions into the future. The future anticipated baseline approach accomplishes this by first establishing a BAU baseline scenario (with established levels of biogenic feedstock demand from stationary sources) and uses this as an emissions benchmark of biogenic feedstock use based on a specific set of anticipated future environmental and socioeconomic conditions. The BAU projection is then compared with a simulated alternative future scenario (or scenarios) that incorporates the same set of anticipated future environmental and socioeconomic conditions as the BAU baseline scenario and only a single specific change (e.g., increase or decrease) in biogenic feedstock demand.

[3] AEO projections are used as part of the baseline and scenario construction in other appendices of this report. However, it is important to remember that estimates of future possible biomass supply results from AEO as well as other reports cited here cannot be compared directly with the results produced using the proposed method in this appendix because of the evaluation of different feedstocks, different end users, and other evaluation parameters.

The resulting difference between these scenarios indicates possible impacts of biogenic feedstock use.

2.4. Limitations and Implications of the Future Anticipated Baseline Approach

Although models are useful for gauging the responsiveness of complex economic systems and providing insights into potential responses to policy or actions, all models have associated uncertainties and limitations. This is especially true for intertemporal optimization models in which optimal economic decisions are influenced by expectations of future market and policy conditions. Results from economic optimization models are sensitive to the selection of model functions and parameters (e.g., biophysical yield parameters or demand elasticities) as well as scenario assumptions. There are also inherent uncertainties regarding input data, parameters, and model structure (in the historical data as well as future expectations). In addition, model scenario results are not predictions of the future. Instead, they should be viewed as providing insights as to what may happen under scenarios of plausible potential futures.

Future anticipated baselines allow for consideration of potential intermediate and distant futures where economic drivers may fall outside of historic ranges of data or where there is no experience with specific policies. In the case of forestry, a longer-term analysis (i.e., 40 years or greater) is often necessary to capture biophysical considerations (e.g., growth rates, rotation periods) and related investment behavior. Simulation models are often designed to consider long-run potential outcomes that tend to fall outside of historic experience.

Although longer time frames offer the advantage of capturing long-term investments for natural resource systems with long biological growth intervals, economic and physical uncertainties grow with longer time frames. Given the size and complexity of many intertemporal optimization models, characterizing uncertainty through Monte Carlo analysis or stochastic dynamic programming creates computational difficulty. Thus, uncertainty is often evaluated through sensitivity analysis by adjusting key parameters across multiple scenarios (i.e., evaluating multiple future anticipated baselines or deviations from a common baseline). Sensitivity analysis can be used to test the impacts of different assumptions employed in the model, including assumptions about future economic conditions or policies.

3. Key Design Elements to Consider

A future anticipated baseline approach application requires information about biomass production systems and associated CO_2 emissions as well as the demand system and related economic factors. The data inputs, model parameters, and assumptions about the BAU and counterfactual trajectories all play significant roles in determining results. The analysis in this section includes consideration of desired model framework/function types, future macroeconomic conditions (i.e., population, gross domestic product), and relevant sector representation. It also considers capabilities for representing future potential biophysical conditions, the land use and energy sectors, land use and commodity competition, and GHG accounting. If all of these components and model functions cannot be included in the assessment, there will be trade-offs and resulting implications.

The list below illustrates the key components to be considered in a modeling platform for simulating anticipated baselines. Each of these components is discussed in the following subsections:

- Model function types and model dynamics (economic optimization, intertemporal or recursive dynamic);
- Anticipated future conditions (macroeconomic, biophysical);
- GHG emissions representation;
- Forest sector representation;
- Agricultural sector representation;
- Land use competition;
- Energy sector representation; and
- International representation.

3.1. Model Function Types and Model Dynamics

3.1.1. Modeling Scope: Economic Optimization

In the context of this framework, a model should have a detailed biophysical component to evaluate biogenic emissions, be well grounded in economic theory, and represent the benefits, costs, and opportunity costs associated with land management and biomass processing alternatives. A suitable model or set of models should allocate resources and economic inputs to production and consumption processes that achieve the highest net economic return. This attribute is essential because it is consistent with rational economic behavior, and allows for the inclusion of autonomous adaptation to changing conditions through incentives. By optimizing net returns to economic welfare-producing activities, a model allocates resources efficiently to produce final economic goods and services. For models with a direct linkage to land use systems, optimization helps reflect the opportunity costs of different land use and/or management alternatives, with implications for future management decisions.

Different modeling frameworks are appropriate for different research questions. Generally speaking, if a broader look at the overall economy is necessary for an analysis, then an economy-wide computable general equilibrium (CGE) model may be used. If specific sectors should be evaluated in detail, such as forestry and/or agriculture, then a sectoral partial equilibrium (PE) model may be chosen.

A number of studies evaluate the trade-offs and implications of employing either CGE or PE models to evaluate the impacts of biomass (liquid or solid) production for energy. General trade-offs for using different modeling types for climate and land use policy evaluation are examined in Van der Werf and Peterson (2009). Kretschmer and Peterson (2008) present a thorough review of CGE models integrating bioenergy as well as some discussion of PE models (mostly those focusing on the agriculture sector in the context of transportation fuels).

In the context of bioenergy, CGE models can evaluate the direct and indirect impacts of activities or policy shocks across a variety of sectors and, in the case of global models, across countries. This modeling approach can be useful for analyzing overall impacts of bioenergy but may not have the ability to look at the level of geographic, biophysical, or other sector-specific details that may be necessary. PE models can offer detailed information for the sector(s) being evaluated (in this context, agriculture and forestry sectors) but do not include all sectors of the economy and cannot provide a complete picture of macroeconomic impacts. There are variations between CGE and PE models as well to consider. For example, as Kretschmer and Peterson (2008) pointed out, FASOM-GHG differs from other PE models in that it covers both agriculture and forestry (most other PEs currently focus on one or the other) and includes uses for biomass other than liquid biofuels. Latta et al. (2013) applied FASOM-GHG to assess the market, land use, and GHG implications of biomass electricity expansion. The authors evaluated different CGE and PE models used to model forest-derived biomass use for energy.

3.1.2. Temporal Dynamics

A future anticipated baseline simulation would ideally be based on expectations of future market conditions. To evaluate future biogenic feedstock production trends and potential impacts, a model will need to optimize resource allocation and provide projections over long time horizons. This ability is especially important in order to capture the market and GHG effects of long rotation cycles of forest-derived feedstocks, in addition to other landscape GHG effects that can take decades to unfold (e.g., soil carbon pool impacts, decay rates). The need for long time frames implies use of either intertemporal optimization or recursive dynamic models. Static (single time period) models are not considered for use here, although in certain contexts they could provide key insights.

Intertemporal optimization models, or models that optimize over a dynamic interval, can be useful for an anticipated future baseline evaluation. Intertemporal models incorporate expectations of future market conditions, and the model solves over a user-defined planning horizon. Economic agents in intertemporal models are forward looking, and management decisions in the present are based on expectations of current and future market conditions. Intertemporal PE or CGE models require that all markets clear simultaneously for all years in the simulation horizon. For instance, a dynamic forestry sector model would choose rotations, product supply, land management intensity, and equilibrium market conditions in order to maximize economic welfare over the full time horizon.

Recursive dynamic models produce projections 1 year at a time, building on the conditions established in the previous year. For example, land deforested in time period *t-1* would be reflected in the initial forestland endowment in period *t*. Anticipated changes in demand and/or prices can be incorporated such that a model continuously faces new biophysical, technological, or economic environmental parameters in each time step. However, decisions in current time periods are not made with expectations of future conditions in mind, so the decision variables in each time period are static in nature. Given the importance of expectations over long planning horizons for forest investment and management decisions, many existing forest models incorporate intertemporal optimization. However, recursive dynamic models could also potentially be used for analyses of forestry, ideally with key anticipated baseline conditions introduced in the model, and forest management in time *t+1* tied to management decisions in time period *t* (e.g., through the incorporation of additional equations based on expected landowner behavior or linkages to other models).

Both intertemporal optimization and recursive dynamic approaches use idealized scenarios of the future. These scenarios are built to reflect perfect competition and information about future markets and conditions as well as optimized markets (where supply equals demand). It is important to recognize that simulations of future scenarios are meant to provide insights about the potential directionality and, in some cases, magnitude of market responses to an activity, target, or other policy shock. Such approaches are best suited for comparing base optimized solutions (i.e., the BAU) with scenario optimal solutions with a shock (alternative scenarios) in order to look at the market impacts between the model solutions.

3.2. Anticipated Future Conditions (Macroeconomic, Biophysical)

Anticipated baseline and alternative scenario analysis include expectations of anticipated macroeconomic and, in the context of accounting of GHG emissions, biophysical conditions. BAU and scenario projections should use published and reputable economic data forecasts, extrapolating only when necessary. Economic projections of population and income exogenously influence demand over time. For example, it makes sense that timber demand is represented not only as a function of price, but also as a function of population and income, and these factors can vary by region. Gross domestic product (GDP) and population estimates can also be introduced to a model to shift the demand curve over time, thus requiring additional timber from the system.[4]

There are several well-known and widely used projections of socioeconomic and physical data to choose from, including those from U.S. EIA and Bureau of Economic Analysis (BEA). Alternatively, one could adopt any number of country-specific projections of key economic variables. At a minimum, simulating an anticipated baseline requires the following economic data:

- GDP projections;
- Population growth projections;
- Demand functions tied to population/income;
- Technological progress assumptions, especially if applicable to stationary sources where efficiency improvements are possible and anticipated;
- Energy market forecasts, especially if energy market data are exogenous to the forestry/land use model; and
- Representation of current and anticipated energy, environmental, or other policies that can constrain BAU trajectories such as renewable portfolio standards (RPS) or the Regulatory Impact Analysis of the Renewable Fuels Standard (RFS2) legislation.

Because some of these data sources are typically only projected over medium time horizons (2035 in the case of the AEO), a consistent method for extrapolating to long-term horizons is required. Defining the relevant time horizon is a determination that will affect the choice of modeling

[4] Note that this could also reduce total demand for timber if regional timber demand is negatively correlated with per capita income for a particular country/region.

procedures to estimate the impacts of using biogenic feedstocks for energy. For woody biomass, a future anticipated baseline methodology would require a long time horizon (40 years or greater) that fully captures forest rotation time frames. For agriculture, a shorter time frame might be sufficient, although a longer time frame would allow one to examine perennial biomass or short rotation woody crops that take several years to reach maturity.

Future anticipated baseline and alternative scenario analysis also requires information about future expected biophysical conditions, such as forestry and agricultural productivity, and landscape and carbon cycle dynamics. Specifically, this information includes parameterization of forest growth curves by class and region as well as biophysical limits to productivity, which can include climate change or environmental conditions (e.g., anticipated shifts in temperature, atmospheric CO_2, and water availability). Changing environmental conditions could be reflected in yield curves reflective of natural and anthropogenic disturbance risks, due to climate change, increased urbanization, land use changes, or ecological encroachment. Although climate change projections or natural disturbance risks may not be applicable to all accounting applications, it may be necessary to include them in some instances.

3.3. GHG Emissions Representation

Future anticipated baseline modeling requires an assessment of landscape-level emissions changes from an increase or decrease in biogenic feedstock consumption relative to the anticipated baseline. Thus, a modeling framework should directly account for emissions from land management activities across a variety of biogenic feedstock and landscape carbon pools. The choice of modeling framework in large part dictates the complexity available for GHG accounting. The degree of detail in GHG pools as well as the emissions associated with land use and land use change activities depends on what sectors of the economy are included in the model and what degree of detail is available in those sectors. Generally speaking, if a broader economy-wide CGE is used, the GHG accounting will be coarse yet comprehensive across the full macro-economy. If a PE model focusing on specific sectors, such as forestry and/or agriculture, should be employed, the level of detail in GHG pools and emissions consequences of specific land use and land use change actions can be included, but at the expense of comprehensive economy-wide coverage.

3.4. Forest Sector Representation

Anticipated future baseline analyses offer the ability to construct and evaluate long-run projections where structural changes are more likely. In the case of forestry, longer-term analysis is often necessary to capture biophysical considerations (e.g., growth rates, rotation periods) as well as the related investment behavior. In the forest sector, decisions about planting and harvest schedules depend in part on expectations about future markets (Sedjo and Tian, 2012).

Forest sector representation should, to the extent possible, be based on observed demand rates for forest products. Future supply and demand can then be determined endogenously through intertemporal optimization under anticipated future macroeconomic conditions. Underlying datasets include historic price and quantity demanded data for forestry products such as timber, pulp/paper, biomass, pellets, etc., as well as demand projections for calibration. Note that, in some instances, it might be preferable to model specific biomass demand assumptions as given in the baseline. The modeling framework should also have comprehensive wood product market representation (including raw timber, pulp/paper, and processed wood products). Ideally, product demand would vary by production region. In addition, the modeling platform should depict growth rates and harvest schedules that vary by region, species, and management regime. Management regime (or intensity) is especially important because intensification of forest stands can alter the carbon intensity of the biomass. Depicting the costs and utilization potential of forest logging and milling residues is another important modeling attribute for future anticipated baseline modeling in this context. Forest residues are an important source of biogenic feedstock supply, and the emissions profile of residues post-harvest may need to be tracked (as discussed in Appendices H and K).

3.5. Agricultural Sector Representation

Similar to the forestry sector, the modeling framework should represent agricultural sector production possibilities, markets, and land management options. Output prices modeled endogenously would allow for supply-side responses and reallocation of resources in response to demand shocks. The livestock sector should also be represented, with explicit linkages to the crop sector through the market for animal feed sourced from agricultural crops and by-products. In addition to conventional commodity production possibilities, models should be representative of dedicated energy crop possibilities and crop residuals as potential biomass feedstock sources. This would include representation of the land requirement, costs of harvesting, transporting, and storing the energy biomass prior to combustion.

3.6. Land Use Competition

Additionally, the modeling framework should depict land use competition among alternative uses (timberland, cropland, grazing land), allowing for endogenous land use shifts in response to changing market and policy conditions. Furthermore, a model should be able to simulate regional or global supply-side responses to changes in biomass demand, feedstock prices, or renewable energy prices from baseline levels. For instance, the modeling framework would allow for projections to simulate how requiring *X* tons of biomass energy per year in the Southeastern United States might affect forest land use decisions locally, in the Pacific Northwest (regionally), and/or globally. For an economic model, supply-side response potential should be reasonably constrained according to the biophysical nature of the system. That is, although supply might be particularly responsive to price/demand changes, physical constraints such as land availability, biophysical growth capacities, or infrastructure limitations could constrain regional responses to a market change. Developing land constraints that reflect current activities can help account for these factors, though such constraints limit flexibility when projecting into the future. Such functionality allows for evaluation of overall potential landscape land use changes (direct and/or indirect land use change) and related GHG impacts. Latta et al. (2013) highlighted the importance of land use competition between the forestry and agricultural sectors for projecting the potential GHG effects of biomass electricity expansion in the United States.

3.7. Energy Sector Representation

Forestry and/or land use models typically do not endogenously capture energy market impacts of different policy scenarios that may affect biomass demand. Forestry and land use models can be excellent tools for estimating biomass supply (and subsequent environmental impacts) under exogenously defined policy scenarios (volumetric mandate or price incentive). However, such models currently do not capture the spillover effects of increased biomass energy demand/consumption in other sectors of the economy (including energy sectors). Without explicitly accounting for these sectors, one cannot reflect the true demand for woody biomass and the competition between biomass and other renewable energy sources under policy-induced shifts from an anticipated baseline. That is, although existing forestry and land use models can simulate biomass production pathways, this may not accurately reflect the fuel mix that will result from a change in policy or energy market conditions. Therefore, it is important to calibrate land use models to projected energy market conditions or existing energy market models.

Also, if a policy or other exogenous change favors investment in a particular non-biomass generation technology, and costs begin to decline because of this investment, the demand for biomass energy would presumably fall. The recent rise in natural gas electricity generation is an example of this scenario and illustrates why modeling deviations from an anticipated baseline in the electricity system are important. If one assumes that biomass demand is tied to the price of renewable energy, then competition among alternative sources matters. This is an important factor that can ultimately affect the estimation procedure for future anticipated baselines in several ways, including those highlighted below.

The rebound effect is an unanticipated policy consequence that has been discussed in the energy economics literature (Greening et al., 2000). Once demand initially declines, the price of fossil energy dips, leading consumers to increase consumption, which reduces the net benefit of the original efficiency improvement. In the case of renewable energy, a policy mechanism that increases the demand for renewable energy can elicit a rebound effect if fossil fuel replacement is high enough to decrease the price of fossil energy.

Another shortcoming of using forestry and land use models with limited energy market interactions is that they likely do not capture competition between competing sources of renewable energy, including different biomass feedstock types. This capability is important because estimation of values for future landscape GHG implications could vary depending on the total amount, and source, of biomass demanded from the system. For instance, if net emissions increase nonlinearly with consumption of a particular feedstock source, it is important to know the total projected demand of biomass energy and the potential emissions impacts. Similar logic flows for systems in which biogenic emissions fall with the level (and price) of bioenergy demanded because of increased terrestrial carbon storage.

3.8. International Representation

An international scope allows for the interaction of U.S. forestry and agricultural markets with the rest of the globe, acknowledging international commodity production, demand, prices, and the associated GHG emissions of that production and consumption. Because many forestry and agricultural markets are globally traded, international commodity prices can affect U.S. land use decisions. Conversely, in the case of some commodities where the United States is a large contributor to the global market, U.S. land use decisions affecting commodity supply can impact global prices and thus international land use decisions and related GHG fluxes. Therefore, a global modeling framework would allow for evaluation of international impacts of changes in U.S. biogenic feedstock demand, including emissions leakage effects. Appendix E provides a detailed discussion of leakage and previous literature that has applied international models to project indirect land use emissions from domestic (U.S.) policies.

3.9. Consideration of Scenario Development

In addition to depicting a future anticipated BAU baseline, the modeling framework should be able to easily calibrate to alternative future scenarios for simulation analysis. That is, if an assessment needs to evaluate the GHG emissions effects of a deviation from anticipated baseline woody biomass harvest regime, what is the appropriate projected baseline and how should an alternative scenario be designed such that a comparison between the two will provide the necessary insights? Numerous examples for how to model future anticipated baselines and alternative scenarios exist, including:

- Define an anticipated baseline with a projected amount of biomass energy demand and compare this against an alternative scenario where total projected biomass energy demand is different (higher, lower, or no biomass consumption) relative to the baseline, holding everything else constant.
- Similarly, define an anticipated baseline with a projected amount of biomass energy demand, but compare that amount against alternative scenarios that exhibit changes (higher or lower) in projected demand for a *single feedstock* (e.g., roundwood) relative to the level of consumption for that feedstock in the anticipated baseline.
- Model a major new policy and compare it to the baseline. This shift could include an aggressive GHG reduction strategy, such as a carbon tax, renewable energy portfolio standard (RPS), or clean energy standard (CES).

Regardless of the scenario implemented, calculation of results will focus on the difference between the future anticipated baseline and the alternative scenario. Furthermore, the chosen modeling approach could vary depending on the alternative scenario evaluated.

For example, one scenario could require an RPS-type policy framework in which a minimum percentage of electricity must be met through renewables. In this example, an energy model could project the proportion of biomass used to help meet the policy-mandated renewable energy demand. Forestry sector models would use this information to determine the final feedstock mix resulting from this demand from the energy sector. Alternatively, one could develop policy scenarios that mandate specific amounts of individual bioenergy feedstocks, and then focus on the GHG implications of each, one at a time. The first approach is somewhat consistent with recently published modeling efforts (Daigneault et al., 2012; Galik and Abt, 2012; Mosnier et al., 2012; Latta et al., 2013), while the latter is consistent with RFS2 legislation. For the purposes of this framework, there is not a specific policy being modeled, nor is there a specific price path (e.g., for energy or CO_2 emissions allowance) or renewable energy target to be met. Therefore, the approach described below differs somewhat from most previous studies in its construction of baselines and alternative scenarios.

4. Modeling Approach and Tools Chosen for Illustrative Framework Applications

The most appropriate modeling approaches and level of detail depend largely on the goals of the assessment. It is important to assess candidate models against considerations appropriate for that application. Ideally, the modeling approach should handle all of the complex interactions necessary to address this complicated issue (many of which have been discussed in previous sections). However, the reality is that a single ideal model does not currently exist. All existing models have various advantages as well as shortcomings that must be taken into account, and the use of one model over another implies trade-offs.

The remainder of this appendix explains the basic methodology developed for this report, focusing on the model attributes used to evaluate biogenic emissions, and the choice of a land use optimization model calibrated to existing energy market projections for this assessment.

This study first uses the most recent biomass consumption rates for energy generation at electricity sector and some industrial sector stationary sources available through the EIA and Department of Energy (from the EIA-923 database, in short dry tons [DOE, 2011]). This analysis then applies the FASOM-GHG model, because it includes most of the key functions and components described in the above section (these functions are described in Section 4.3).

Although FASOM-GHG is not explicitly tied to an energy sector model, biomass projections and energy market assumptions are calibrated to the AEO 2012 forecasts, as described in brief below and in detail in Appendix K that discusses the future anticipated baseline construction methods.

The next subsections briefly describe the anticipated future baseline scenarios and the alternative biogenic feedstock production scenarios to provide context for the application of FASOM-GHG. Details on the baseline scenario development can be found in Appendix K and on the alternative scenario case study applications in Appendix L. The following section describes the key components and capabilities of the FASOM-GHG model, followed by a subsection focusing on specific datasets and functions within FASOM-GHG that are pertinent to this report. Full FASOM-GHG documentation is available online.[5]

4.1. Brief Overview of Baseline Construction

Although there are numerous AEO model scenarios to choose from, the alternative baselines in this study were developed using four AEO 2012 projections and two additional cases:

[5] http://www.cof.orst.edu/cof/fr/research/tamm/forest_and_agriculture_sector_op.htm

- **Reference case:** The Reference case is the baseline AEO 2012 model, which assumes real GDP grows at a 2.4% average annual rate from 2008 to 2035, buoyed by a 1.5% per year growth in productivity in nonfarm businesses and a 0.6% growth in nonfarm employment. All the other scenarios pivot off of the Reference case scenario, changing specific assumptions.
- **High GDP Growth case:** The AEO 2012 High Economic Growth case assumes that real GDP grows by 3%, supported by productivity growth of 2.4% and employment growth of 1.2%.
- **Low GDP Growth case:** The AEO 2012 Low Economic Growth case assumes that real GDP grows by 1.8%, supported by productivity growth of 1.5% and employment growth of 0.5%.
- **Low Renewable Technology Cost case:** The AEO 2012 Low Renewable Technology Cost case assumes annual levelized cost for non-hydropower renewables is 10% lower than the Reference case in 2010 and is 35% lower by 2035 compared with Reference case values.
- **Zero Biomass case:** A constraint is imposed that restricts all biomass consumption for energy generation in each region.
- **Constant Biomass case:** The Constant Biomass scenario begins with total biomass demand constraints set to 2009 consumption levels.

Using these scenarios to derive biogenic feedstock demand projections for stationary sources, regional constraints are imposed requiring supply-side utilization of biomass for energy generation that matches these projections exactly. No restrictions are imposed on regional feedstock mixes used to meet these overall biomass requirements. The model minimizes the costs of providing the requisite biomass. It is important to acknowledge that this study uses the 2009 EIA AEO information to be consistent with the other databases used (the most recent Emissions and Generation Resource Integrated Database [eGRID] at the time of this work was from 2009).

Most dynamic models, particularly energy sector models, are calibrated to existing economic forecasts. This analysis adopts key forecasts from the AEO. Thus, anticipated market and policy conditions are consistent with assumptions underlying the AEO and the National Energy Modeling System (NEMS). Energy price projections are calibrated to the AEO 2012 to reflect anticipated energy market conditions. Biogenic feedstock consumption projections are also calibrated to growth rates in renewable energy demand in the industrial and electricity sectors. An advantage of calibrating scenarios to the AEO is that existing state policies (RPS, CES, etc.) are already accounted for to the extent possible. Thus, growth parameters for renewable energy demand used in this analysis assume that state-level policies encouraging growth in renewable electricity will hold. Additional discussion on the specific scenarios chosen for this report can be found in Appendix K.

4.2. Brief Overview of Regional Feedstock Case Studies

The following illustrative case studies are developed to focus on the net biogenic CO_2 effects of an increase in biogenic feedstock consumption for a specific feedstock within a particular region, relative to the future anticipated future baseline. These case studies, representing different feedstock types and different regions in the United States in order to illustrate regional and feedstock differences, offer insight into the potential landscape emissions impact of increased consumption of a single biogenic feedstock:

- Southeast roundwood;
- Corn Belt corn stover; and
- Pacific Northwest logging residues.

In each region, the demand for the specified feedstock is increased 1 million tons per year above biomass demand in the AEO Reference case level by 2030. For example, roundwood demand in the Southeast increases by 1 million tons in relation to the AEO-based baseline. All feedstock scenario results are calculated relative to the AEO Reference case and Zero Biomass case. Additional information on how these case study scenarios were developed and executed in FASOM-GHG, as well as variations on these case study evaluations, can be found in Appendices K and L. Some of the feedstock-specific case study sensitivities were chosen to maintain consistency with the reference point case studies evaluated in this report and are reported in Appendix L.

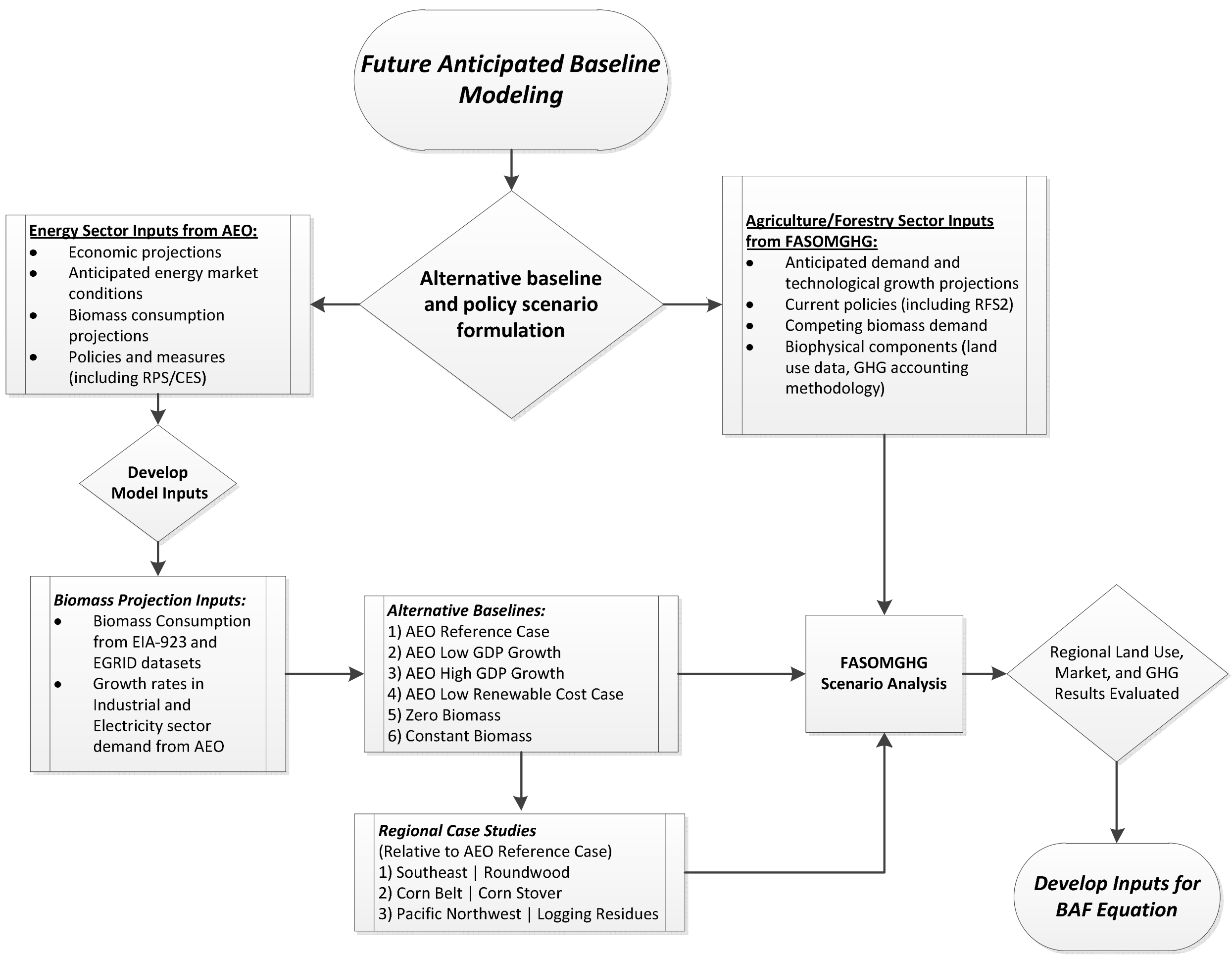

Figure 1. Conceptual Diagram Outlining the Basic Anticipated Future Baseline Modeling Approach Presented in this Appendix.

4.3. Use of FASOM-GHG

FASOM-GHG has the basic necessary capabilities and characteristics to satisfy the requirements of this study. Table 1 highlights these abilities, which are discussed in detail in the following sections.

Table 1. FASOM-GHC Attributes.

Attribute	FASOM-GHG
Model framework/function type	Intertemporal partial equilibrium
Anticipated future conditions	AEO 2012 energy market conditions, USDA baseline (2010), and 2005 RPA Assessment
GHG representation	CO_2, CH_4, and N_2O accounting across forest, crop, and livestock management activities; CO_2 accounting includes biogenic feedstock (forest carbon) and non-biogenic feedstock (soil) pools
Forest sector representation	Logs from timber harvest and secondary wood products, forest residues
Agricultural sector representation	40 primary crop commodities; 25 primary livestock products; 32 domestic and imported forest logs; 12 categories of forest and agricultural residues; 17 secondary crop products; 17 secondary livestock products; 10 processing by-products; 40 processed forest products
Land use competition	Endogenous competition between cropland, forestland, and grazing lands
Energy sector representation	Ethanol (first and second generation), biodiesel, and biopower (100% biomass generation or co-firing levels of 5%, 10%, 15%, and 20%) with exogenous price or quantity constraint
International representation	18 regions for seven agricultural traded commodities; forest sector includes endogenous activities for trade with Canada as well as other significant trade flows (e.g., softwood lumber trade with non-Canadian regions)

4.3.1. Overview of Key FASOM-GHG Attributes and Functions

This analysis applies an updated and enhanced version of FASOM-GHG. FASOM-GHG is a dynamic partial equilibrium economic model of the U.S. agricultural and forestry sectors and has been applied in a wide range of policy settings. FASOM-GHG explicitly models GHG mitigation strategies, including many bioenergy processing options (Murray et al., 2005; Schneider and McCarl, 2003).

FASOM-GHG uses a price-endogenous mathematical programming approach developed by Judge and Takayama (1973) and McCarl and Spreen (1980). The model maximizes total intertemporal welfare across the U.S. agricultural and forestry sectors, or the sum of producer surplus (area below the equilibrium price) and consumer surplus (area above the equilibrium price). Commodity and most factor prices are endogenous, determined by the supply and demand relationships in all markets included within the model. The framework accounts for market adjustments over time to systematic policy shocks by depicting changes in equilibrium prices and quantities supplied of all primary and secondary commodities. Because commodity markets within agriculture and forestry are highly interdependent, a systematic shock that disrupts the optimal production portfolio of one commodity (e.g., corn) can cycle through other primary or secondary commodity markets (such as ethanol and livestock, which use corn as a critical factor input, or corn substitutes such as alternative feed grains), through competition for production inputs, consumers, trading partners, and land.

FASOM-GHG accounts for a comprehensive range of land use categories consistent with land classifications from multiple resources including the Natural Resources Inventory (NRCS, 2003), Major Land Use Database (USDA-ERS, 2010), and agricultural census (USDA-NASS, 2010). The model allows for explicit land use competition between cropland, grazing lands, and conservation lands (CRP) and forestland based on expected returns to alternative uses. This allows us to simulate potential land use change impacts of policy drivers that increase the relative value of land holdings in a particular use over time (Alig et al., 1998, Alig et al., 2010) and is a departure from the static CGE modeling approach that assumes conversion costs or elasticities of substitution between alternative land uses.

FASOM-GHG is disaggregated into 63 minor production regions in the lower 48 states and 11 main agro-forestry regions. Table 2 displays all major regions with accompanying production units. All major regions include crop and forestry production opportunities except for the Great Plains and Southern Plains (which includes most of Texas and Oklahoma). Land use change between forestry and agriculture is restricted to lands that fall within a certain land suitability class, thus ensuring that land transfers remain within realistic bounds (Alig et al., 2010).

Table 2. Definition of FASOM-GHG Production Regions and Market Regions.

Key	Market Region	Production Region (States/Subregions)
NE	Northeast	Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, West Virginia
LS	Lake States	Michigan, Minnesota, Wisconsin
CB	Corn Belt	All regions in Illinois, Indiana, Iowa, Missouri, Ohio (IllinoisN, IllinoisS, IndianaN, IndianaS, IowaW, IowaNE, IowaS, OhioNW, OhioS, OhioNE)
SE	Southeast	Virginia, North Carolina, South Carolina, Georgia, Florida
SC	South Central	Alabama, Arkansas, Kentucky, Louisiana, Mississippi, Tennessee, Eastern Texas
SW	Southwest (agriculture only)	Oklahoma, all of Texas but the eastern part (Texas High Plains, Texas Rolling Plains, Texas Central Blacklands, Texas Edwards Plateau, Texas Coastal Bend, Texas South, Texas Trans Pecos)
RM	Rocky Mountains	Arizona, Colorado, Idaho, Montana, Nevada, New Mexico, Utah, Wyoming
PSW	Pacific Southwest	All regions in California (CaliforniaN, CaliforniaS)
PNWE	Pacific Northwest-East side	Oregon and Washington, east of the Cascade mountain range

PNWW	Pacific Northwest- West side (forestry only)	Oregon and Washington, west of the Cascade mountain range

Figure 2. Map of the FASOM-GHG Regions (Source: Beach et al., 2010b).

Land to development transfers are modeled on a regional basis by land type and drawn from data prepared for the 2010 Resources Planning Act (RPA) Assessment (Alig et al., 2009). These parameters help depict an anticipated future land base that is decreasing in the baseline due to development pressures. Accounting for land to development pressures in an agriculture and forestry sectoral modeling framework is important because varying levels of development pressures can affect land use competition between agriculture and forestry, GHG mitigation potential, and commodity prices (see Alig et al., 2010 for additional discussion).

FASOM-GHG encompasses a suite of GHG mitigation options, including biological sequestration of carbon in agricultural soils and forest stands, alternative crop and livestock production practices to reduce emissions, and bioenergy feedstock substitutes for fossil fuels. The gases represented are carbon dioxide, methane, and nitrous oxide. Forest carbon balances are tracked using a methodology consistent with the Forest Carbon accounting system, FORCARB (Birdsey et al., 2000).

Forest carbon is tracked in trees, soils, understory, and end products. Forest management offset opportunities are endogenously modeled in FASOM-GHG and include avoided deforestation, rotation extensions, altered species mix, partial thinning, and reforestation. For a discussion of GHG accounting and mitigation options, as well as forestry and agricultural management options in FASOM-GHG, see Beach et al. (2010b).

The model allows for intensive and extensive margin shifts for both crop and forestry production activities (as discussed in Baker et al., 2013). Furthermore, land use competition and product substitution between the two sectors is a key model component, missing from other partial equilibrium models of the agriculture and forestry sectors. The inclusion of such a function has been found to have a dramatic impact on GHG emissions trajectories relative to less inclusive modeling approaches (Latta et al., 2013). Additional information on how FASOM-GHG depicts intensive and extensive margin production opportunities in forestry and agriculture can be found in Beach et al. (2010a) and Adams et al. (2008).

FASOM-GHG incorporates endogenous international trade effects, such as international supply regions (18 regions) for seven agricultural traded commodities with import supply functions (Adams et al., 2008). The forest sector includes endogenous activities for virtually all forms of trade with Canada as well as other significant trade flows to offshore regions (e.g., softwood lumber trade with non-Canadian regions). Details on FASOM-GHG's international components are discussed in the supplemental online documentation (Beach et al., 2010b; Adams et al., 2008). FASOM-GHG cannot conduct detailed analysis of global GHG impacts of changes in U.S. biogenic feedstock production and consumption. However, the model could be linked with a global model, including forestry and agricultural trade components with related land use and GHG accounting components.

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