



Thank you for downloading a chapter from the “*2016 Billion-Ton Report: Advancing Domestic Resources for a Thriving Bioeconomy, Volume 2: Environmental Sustainability Effects of Select Scenarios from Volume 1*”.

Please cite as follows:

U.S. Department of Energy. 2017. *2016 Billion-Ton Report: Advancing Domestic Resources for a Thriving Bioeconomy, Volume 2: Environmental Sustainability Effects of Select Scenarios from Volume 1*. R.A. Efroymsen, M.H. Langholtz, K.E. Johnson, and B.J. Stokes (Leads), ORNL/TM-2016/727. Oak Ridge National Laboratory, Oak Ridge, TN. 642p. doi: 10.2172/1338837.

This report, as well as supporting documentation, data, and analysis tools, can be found on the Bioenergy Knowledge Discovery Framework at [bioenergykdf.net](http://bioenergykdf.net).

Go to <https://bioenergykdf.net/billionton2016/vol2reportinfo> for the latest report information and metadata for volume 2 or <https://bioenergykdf.net/billionton2016/reportinfo> for the same for volume 1.

Following is select front matter from the report and the selected chapter.

# 2016 BILLION-TON REPORT

## Advancing Domestic Resources for a Thriving Bioeconomy

---

A Study Sponsored by U.S. Department of Energy  
Office of Energy Efficiency and Renewable Energy  
Bioenergy Technologies Office

### Volume 2:

Environmental Sustainability Effects of Select Scenarios from Volume 1

January 2017

*Prepared by*

OAK RIDGE NATIONAL LABORATORY  
Oak Ridge, Tennessee 37831–6335 managed by  
UT-Battelle, LLC  
for the  
U.S. DEPARTMENT OF ENERGY

### Citation :

U.S. Department of Energy. 2017. *2016 Billion-Ton Report: Advancing Domestic Resources for a Thriving Bioeconomy, Volume 2: Environmental Sustainability Effects of Select Scenarios from Volume 1*. R. A. Efroymson, M. H. Langholtz, K.E. Johnson, and B. J. Stokes (Eds.), ORNL/TM-2016/727. Oak Ridge National Laboratory, Oak Ridge, TN. 640p. doi 10.2172/1338837

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, expressed or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof. This report is being disseminated by the Department of Energy. As such, the document was prepared in compliance with Section 515 of the Treasury and General Government Appropriations Act for Fiscal Year 2001 (Public Law 106-554) and information quality guidelines issued by the Department of Energy. Further, this report could be “influential scientific information” as that term is defined in the Office of Management and Budget’s Information Quality Bulletin for Peer Review (Bulletin). This report has been peer reviewed pursuant to section II of the Bulletin.

## Availability

This report, as well as supporting documentation, data, and analysis tools, can be found on the Bioenergy Knowledge Discovery Framework at [bioenergykdf.net](http://bioenergykdf.net). Go to <https://bioenergykdf.net/billionton2016/vol2reportinfo> for the latest report information and metadata.

## Additional Information

The U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy's Bioenergy Technologies Office and Oak Ridge National Laboratory provide access to information and publications on biomass availability and other topics. The following websites are available:

[energy.gov](http://energy.gov)

[eere.energy.gov](http://eere.energy.gov)

[bioenergy.energy.gov](http://bioenergy.energy.gov)

[web.ornl.gov/sci/transportation/research/bioenergy/](http://web.ornl.gov/sci/transportation/research/bioenergy/)

Front cover images courtesy of ATP<sup>3</sup>, Oak Ridge National Laboratory, Abengoa, Solazyme, and BCS, Incorporated.

### DISCLAIMER

The authors have made every attempt to use the best information and data available, to provide transparency in the analysis, and to have experts provide input and review. However, the *2016 Billion-Ton Report* is a strategic assessment of potential biomass (volume 1) and a modeled assessment of potential environmental effects (volume 2). It alone is not sufficiently designed, developed, and validated to be a tactical planning and decision tool, and it should not be the sole source of information for supporting business decisions. *BT16* volume 2 is not a prediction of environmental effects of growing the bioeconomy, but rather, it evaluates specifically defined biomass-production scenarios to help researchers, industry, and other decision makers identify possible benefits, challenges, and research needs related to increasing biomass production. Users should refer to the chapters and associated information on the Bioenergy Knowledge Discovery Framework ([bioenergykdf.net/billionton](http://bioenergykdf.net/billionton)) to understand the assumptions and uncertainties of the analyses presented. The use of tradenames and brands are for reader convenience and are not an endorsement by the U.S. Department of Energy, Oak Ridge National Laboratory, or other contributors.

The foundation of the agricultural sector analysis is the USDA Agricultural Projections to 2024. From the report--“Projections cover agricultural commodities, agricultural trade, and aggregate indicators of the sector, such as farm income. The projections are based on specific assumptions about macroeconomic conditions, policy, weather, and international developments, with no domestic or external shocks to global agricultural markets.” The *2016 Billion-Ton Report* agricultural simulations of energy crops and primary crop residues are introduced in alternative scenarios to the 2015 USDA Long Term Forecast. Only 2015-2024 Billion-Ton national level baseline scenario results of crop supply, price, and planted and harvested acres for eight major crops are considered to be consistent with the 2015 USDA Long Term Forecast. Projections for 2025–2040 in the *2016 Billion-Ton Report* baseline scenario and the resulting regional and county level data were generated through application of separate data, analysis, and technical assumptions led by Oak Ridge National Laboratory and do not represent nor imply U.S. Department of Agriculture or U.S. Department of Energy quantitative forecasts or policy. The forest scenarios were adapted from U.S. Forest Service models and developed explicitly for this report and do not reflect, imply, or represent U.S. Forest Service policy or findings. The Federal Government prohibits discrimination in all its programs and activities on the basis of race, color, national origin, age, disability, and, where applicable, sex, marital status, familial status, parental status, religion, sexual orientation, genetic information, political beliefs, reprisal, or because all or part of an individual's income is derived from any public assistance program.



# 01 | Introduction



Kristen Johnson,<sup>1</sup> Rebecca Efroymson,<sup>2</sup> and  
Matthew Langholtz<sup>2</sup>

<sup>1</sup> U.S. Department of Energy

<sup>2</sup> Oak Ridge National Laboratory

## 1.1 Background

With the goal of informing national bioenergy and bioproducts research, development, and deployment strategies, the 2016 *U.S. Billion-Ton Report: Advancing Domestic Resources for a Thriving Bioeconomy (BT16)*, is the third in a series of national biomass resource assessments commissioned by the U.S. Department of Energy (DOE). The *BT16* report is composed of two volumes. Volume 1 focuses on biomass resource analysis (i.e., the potential economic availability of cellulosic and other feedstocks under specified market scenarios) as an update to the two previous Billion-Ton reports, i.e., the *2005 Billion-Ton Study* (Perlack et al. 2005) and the *2011 Billion-Ton Update (BT2)* (DOE 2011). In *BT16* volume 1, supplies are quantified under specified constraints. *BT16* volume 2, this report, investigates potential environmental effects of producing biomass supplies for a small set of scenarios simulated in volume 1.

Increasing biomass use can create economic opportunities, enhance energy security, and provide environmental benefits (Rogers et al. 2016). Federal policies aim to foster increased biomass utilization, focusing on growth of second-generation cellulosic biofuels. A report by EPA (2011) concluded that environmental effects of biomass use in the future will be determined by the choice of feedstock, land use change, cultivation, and conservation practices. *BT16* volume 2 investigates a range of these factors to improve understanding of potential environmental outcomes associated with increased biomass production.

Most analyses in volume 2 simulate environmental effects of potential agricultural and forestry biomass production at the county level.<sup>1</sup> The land-use (i.e., land management) change assumptions associated with the scenario transitions are described and discussed, including the assumption and modeling constraint that the agricultural and forestry land bases remain constant during the simulation period. This volume also presents a qualitative analysis of environmental effects of algae production under carbon dioxide (CO<sub>2</sub>) co-location scenarios, as well as an analysis of climate sensitivity of agricultural feedstock productivity under a set of potential future scenarios. Finally, strategies to enhance environmental outcomes are described.

Several constraints designed to maintain aspects of environmental quality are employed in volume 1, carried over from the 2011 *BT2*. These constraints include assumptions about tillage classes, residue availability, irrigation, and land-exclusion areas. Supply constraints are summarized in chapter 2 and are described in more detail in *BT16* volume 1. Some of these constraints reduce the national potential biomass supply estimates in volume 1 when compared to biomass potential without these constraints. Despite these supply reductions, volume 1 illustrates a situation where large volumes can be produced while not using environmentally sensitive lands or exacerbating soil erosion. However, more thorough analyses are required to estimate possible environmental effects of producing the potential biomass supplies simulated in *BT16* volume 1, and to determine how different types of environmental effects could vary across locations, years, biomass type, biomass yield increase rates, and management practices.

<sup>1</sup> The potential benefits of utilizing biomass wastes for energy (after reduce, reuse, and recycling options have been exhausted) are described in chapter 14 but are not evaluated quantitatively in this volume. Environmental effects of algae biomass are described qualitatively in chapter 12.



## 1.2 Objectives

*BT16* volume 2 seeks to (1) advance the discussion and understanding of environmental effects that could result from significant increases in U.S. biomass production and (2) accelerate progress toward a sustainable bioeconomy by identifying actions and research that could enhance the environmental benefits while minimizing negative impacts of biomass production.

In previous DOE-funded research, indicators were identified that support evaluation of environmental sustainability for a variety of bioenergy systems (McBride et al. 2011; Efrogmson and Dale 2015). For this study, environmental indicators were selected in the categories of soil carbon, greenhouse gas (GHG) emissions, water quality, water quantity, biodiversity, and air emissions (see section 1.3). *BT16* volume 2 also includes a discussion of land-use (i.e., land management) change assumptions associated with the scenario transitions (but not including analysis of indirect land-use change [LUC]), analyses of climate sensitivity of feedstock productivity under a set of potential scenarios, and a qualitative assessment of environmental effects of algae production under CO<sub>2</sub> co-location scenarios.

*BT16* volume 2 is not a prediction of environmental effects of growing the bioeconomy, but rather, it evaluates specifically defined biomass-production scenarios to help researchers, industry, and other decision makers identify possible environmental benefits, opportunities, and limitations related to increasing biomass production at the local, regional, and national levels. For example, the analyses in this volume can help identify where care should be taken when producing certain feedstocks or where further safeguards are needed to prevent or mitigate potential negative impacts of commercial scale production. Results can also help stakeholders identify locations that are more or less appropriate for certain feedstocks given local conditions, or possible issues that will require further research, monitoring, and adaptive management.

Terrestrial biomass supply projections were simulated in volume 1 using the Policy Analysis System model for agriculture and the Forest Sustainable and Economic Analysis Model for forestry. *BT16* assumptions hold total forestland and total agriculture lands constant throughout the simulation period. Chapter 2 provides a summary of the methodology used to generate the data in volume 1 that are analyzed in volume 2.

It is important to note that the biomass supply potentials presented in volumes 1 and 2 are policy-independent and based on specified price and yield scenarios as well as guiding principles that reflect certain environmental and socioeconomic considerations. For example, some principles aim to maintain environmental quality, such as improved tillage and residue-removal practices, exclusion of irrigation, and reserved land areas to protect biodiversity and soil quality. In this sense, this report may differ from other efforts seeking to depict potential biomass demand and related market, environmental, and land-use interactions under business-as-usual (BAU) scenarios or other specific policy conditions. Further, the scenarios represent total potential biomass production at a market price of \$60 per dry ton regardless of end use. Because future end uses may be some unknown mix of biofuels, biopower, and bioproducts, this report presents the biomass supplies as being potentially available for these end uses, but the analysis of environmental effects is limited to production, preprocessing, and delivery of the supplies.

### 1.2.1 Scenarios

Most chapters in volume 2 analyze three biomass scenarios from volume 1 or a subset of these, such as focusing only on agricultural or only on forestry scenarios. These scenarios assume a price of up to \$60 per dry ton at the roadside (i.e., prior to transport, storage, and processing at a biorefinery). This price point is potentially viable and could provide more

than 1 billion tons<sup>2</sup> of biomass by 2040. The scenarios include

- **BC1&ML 2017:** 2017 base-case agricultural combined with baseline forestry scenarios: 326 million dry tons<sup>3</sup>
- **BC1&ML 2040:** 2040 base-case agricultural combined with baseline forestry scenarios: 807 million dry tons
- **HH3&HH 2040:** 2040 3% high-yield agricultural combined with HH forestry scenarios: 1.1 billion dry tons.

In these scenarios, BC1 and HH3 are agricultural scenarios and ML and HH are forestry scenarios.

Chapter 2 provides a description of these scenarios. The scenarios were selected to assess and compare potential environmental effects during two time periods with two potential agricultural yield-increase assumptions for the latter year (2040). Potential near-term biomass production is represented in the

2017 scenarios, and significantly expanded biomass production that could occur is represented in the 2040 scenarios. Differences in environmental effects between relatively low and potentially high levels of annual biomass production can be considered by comparing the 2017 and 2040 scenarios. Yield-based environmental effects can be shown by comparing the two 2040 scenarios, given that future biomass availability would greatly depend on yield growth and other technological improvements. For more information on the base-case and high-yield scenarios, see chapter 2 or volume 1. Alternative future scenarios are possible.

In the scenarios identified above, resources evaluated in volume 2 are a subset of the potential resources identified in volume 1. The resources evaluated in volume 2 exclude waste resources and include only corn ethanol and soybean biodiesel portions of currently used resources. Total potential supplies identified in volume 1 and the subset of those supplies analyzed in volume 2 are identified in table 1.1.

**Table 1.1** | Biomass Supplies Identified in *BT16* volume 1 and Evaluated in volume 2 for Select Scenarios and Years (in Million Dry Tons)

	Identified in volume 1			Evaluated in volume 2		
	BC1&ML 2017	BC1&ML 2040	HH3&HH 2040	BC1&ML 2017	BC1&ML 2040	HH3&HH 2040
<b>New potential</b>	343	826	1,154	192	669	997
<b>Currently used</b>	365	365	365	134	138	139
<b>Total</b>	709	1,192	1,520	326	807	1,136
<b>Notes</b>	New potential and currently used resources include agricultural and forest biomass and waste resources.			New potential includes agricultural and forest biomass only. Currently used resources include only corn ethanol and soybean biodiesel portions. Waste resources are excluded.		

<sup>2</sup> Here and elsewhere in the report, tons are reported as dry short tons, unless specified otherwise.

<sup>3</sup> The terms base case and baseline have specific meanings in *BT16* that may differ from definitions in other studies.

This study does not include a simulated 2040 BAU scenario because of data limitations and uncertainties about multiple sectors in the future that are outside the scope of this study. The 2017 scenario may represent some characteristics of a future BAU scenario because the former scenario includes only currently available resources (i.e., agricultural residues and forestland resources) with production of conventional crops maintained at current levels. However, the scenario does not include several important characteristics of a BAU case, such as future changes in overall demand, market impacts, and crop yields.

The distribution of potential biomass across the nation in the scenarios reflects the assumption that the total agricultural-land base and the total forestland base do not change between the present and 2040. Modifying scenarios to allow transitions between these major land classes could result in different estimates of environmental effects.

Certain indicators evaluated in this report, including air emissions and GHG emissions, could be affected not only by biomass production, but also by biomass harvest and transportation. To enable analyses of these indicators, logistics inputs (e.g., diesel) were estimated using the Supply Characterization Model (SCM). For the three scenarios, SCM was used to simulate distribution of potential biomass resources to a national grid of hypothetical biorefinery locations and to simulate associated fossil fuel consumption based on current road networks. The application of SCM is described in chapter 6 of *BT16* volume 1 and costs estimated in the model are described in section 2.4.4 of this volume.

## 1.2.2 Research Questions

*BT16* volume 2 investigates and reports on the following questions related to potential biomass production in select scenarios:

- What are the LUC implications of the scenarios over time?

- What are the estimated values of environmental indicators and how do those compare among scenarios?
- What are the potential negative environmental effects, and how might they be managed or mitigated?
- What environmental benefits are possible, and under what conditions do they occur?
- Where is more research needed with regard to quantifying effects, enhancing benefits, and preventing negative consequences?
- How sensitive is feedstock productivity to climate?

Comparisons and insights are based on quantification of environmental indicators for the select scenarios.

## 1.3 Environmental Indicators of Bioenergy Sustainability

Sustainability is an aspirational concept that denotes the capacity to meet current needs while maintaining options for future generations to meet their needs. Enhancing sustainability of bioenergy systems is part of the mission of the DOE Bioenergy Technologies Office. Specifically, the Office's strategic goal for bioenergy sustainability is to understand and promote the positive environmental, economic, and social effects and reduce the potential negative impacts of bioenergy production activities (DOE 2016). To make the concept of sustainability operational, consistent approaches are required that facilitate comparable, science-based assessments using measurable indicators of environmental, economic, and social processes (Hecht et al. 2009; McBride et al. 2011; Dale et al. 2013). Progress toward defined sustainability objectives can be estimated using these indicators, which can guide behavior toward those intended outcomes.



Many institutions and researchers have proposed indicators to evaluate sustainability of bioenergy pathways (e.g., Roundtable on Sustainable Biomaterials [RSB 2010]; Global Bioenergy Partnership [GBEP 2011]; and the Council on Sustainable Biomass Production [CSBP 2012]). Building from these efforts, researchers at Oak Ridge National Laboratory selected a generic and practical set of indicators to support environmental sustainability of biomass and bioenergy (McBride et al. 2011). Most of these indicators are modeled in this study (table 1.2). These include indicators of soil carbon, water quality and quantity, GHGs, biodiversity, and air emissions. For the purposes of *BT16* volume 2, these indicators are termed “environmental indicators.”

Appropriate indicators for a particular application depend on the context for their intended use (Efroyms-

son et al. 2013); therefore, the set of indicators from McBride et al. (2011) in table 1.2 is appropriate for some but not all uses. The context of an assessment of environmental effects typically includes the purpose of the assessment, biomass production and distribution systems, end use, policy conditions, stakeholder values, location, temporal influences, spatial scale, baselines, and reference scenarios. This study adopts a slightly modified list of the indicators proposed in McBride et al. (2011) for the purpose of this initial effort to analyze environmental effects of select terrestrial biomass scenarios from volume 1 (table 1.2). Furthermore, a slightly different set of indicators has been proposed to evaluate the environmental effects of algal biofuels (Efroymsson and Dale 2015) and is described in chapter 12.

**Table 1.2** | General Environmental Indicators from McBride et al. (2011) (Numbered) and Indicators Modeled for This Analysis (Light Green)

Indicator category	Indicator
Soil quality	1. Total organic carbon (TOC)
	2. Total nitrogen (N)
	3. Extractable phosphorus (P)
	4. Bulk density
Water quality and quantity	5. Nitrate concentration in streams (and export)
	6. Total phosphorus (P) concentration in streams (and export)
	7. Suspended sediment concentration in streams (and export)
	8. Herbicide concentration in streams (and export)
	9. Storm flow
	10. Minimum base flow
	11. Consumptive water use
Additional: Water yield	
Greenhouse gases	12. CO <sub>2</sub> equivalent emissions (CO <sub>2</sub> and N <sub>2</sub> O)
Biodiversity	13. Presence of taxa of special concern
	14. Habitat area of taxa of special concern
Air quality	15. Tropospheric ozone
	16. Carbon monoxide
	17. Total particulate matter less than 2.5µm diameter (PM <sub>2.5</sub> )
	18. Total particulate matter less than 10µm diameter (PM <sub>10</sub> )
	Additional: VOCs, SO <sub>x</sub> , NO <sub>x</sub>
Productivity	19. Aboveground net primary productivity or Yield

## 1.4 Scope and Scale

The scope of the report is summarized in table 1.3. Agricultural feedstocks include conventional crops, energy crops, and crop residues (fig. 1.1) while forestry feedstocks include logging residues and whole-

tree biomass (fig. 1.2). A subset of these feedstocks is considered in various chapters in this volume. In addition, microalgae are the subject of a qualitative analysis. Most analyses consider production and harvest, while analyses of air emissions and GHG emissions consider transport to the biorefinery as well.

**Table 1.3** | Scope of Terrestrial Biomass Chapters in *BT16* volume 2

Chap	Indicator category	Indicator	Spatial Extent	Biomass	Scenario	Model	Output
4	Soil quality	Soil organic carbon	Conterminous United States	Corn and soybeans for biofuels, wheat, switchgrass, miscanthus, willow, poplar (surrogates for barley, cotton, oats, sorghum, biomass sorghum) <sup>a</sup>	BC1 2017 BC1 2040 HH3 2040	Surrogate CENTURY Soil Organic Carbon model	Soil organic carbon emissions factor (Mg C/ha/yr)
4	GHGs	CO <sub>2</sub> equivalent emissions (CO <sub>2</sub> and nitrous oxide [N <sub>2</sub> O])	Conterminous United States	Corn and soybeans for biofuels, biomass sorghum, energy cane, eucalyptus, loblolly pine, miscanthus, poplar, switchgrass, willow, barley straw, corn stover, oats straw, sorghum stubble, wheat straw, hardwood lowlands (tree), hardwood uplands (tree), mixed wood, softwood natural, softwood planted	BC1&ML 2017 BC1&ML 2040 HH3&HH 2040	Greenhouse gases, Regulated Emissions, and Energy use in Transportation Model (GREET)	GHG intensity (g CO <sub>2</sub> e/dt), GHG emissions (g CO <sub>2</sub> e, tons CO <sub>2</sub> e)
5	Water quality	Total nitrogen loading, nitrate loading, total phosphorus loading, sediment loading	Arkansas-White-Red River Basin (AWR) and Iowa River Basin (IRB)	Corn stover (IRB), miscanthus, willow, switchgrass, energy sorghum, sorghum stubble, poplar, willow, (AWR)	BC1 2040 with conservation practices added	Soil and Water Assessment Tool (SWAT)	Total nitrogen loadings (kg/ha), nitrate loadings (kg/ha), total P loadings (kg/ha), total suspended sediment loading (t/ha), water yield (mm), productivity (t/ha)
6	Water quality	Nitrate loading, total phosphorus loading, sediment loading	Conterminous United States	Whole trees (thinnings and clearcuts)	ML 2017 ML 2040 HH 2040	Empirical model	Regional nitrate, phosphorus, and sediment load response curves (kg/ha), increase over pre-harvest reference
7	Water quantity	Water yield	Conterminous United States	Whole trees (thinnings and clearcuts)	ML 2017 ML 2040 HH 2040	Water Supply Stress Index (WaSSI) Ecosystem Services Model	Annual water yield (gal/yr), seasonal water yield (gal/month), water yield as an incremental percentage, compared to reference

Chap	Indicator category	Indicator	Spatial Extent	Biomass	Scenario	Model	Output
8	Water quantity	Consumptive water use	Conterminous United States	Corn for biofuels, corn stover, soybean to biofuels, wheat straw, switchgrass, miscanthus, willow, poplar, southern pine, softwood and hardwood resources	BC1&ML 2017 BC1&ML 2040 HH3&HH 2040	Water Analysis Tool for Energy Resources (WATER)	Rainwater requirements (gal), (gal/acre); irrigation requirements (gal), (gal/acre)
9	Air emissions	Total particulate matter less than 2.5µm diameter (PM <sub>2.5</sub> ), total particulate matter less than 10µm diameter (PM <sub>10</sub> ), ammonia (NH <sub>3</sub> ), oxides of sulfur (SO <sub>x</sub> ), volatile organic compounds (VOCs), carbon monoxide (CO)	Conterminous United States	Corn, corn stover, sorghum stubble, wheat straw, barley straw, oats straw, switchgrass, miscanthus, hardwood trees, softwood trees, mixed wood trees, hardwood residues, softwood residues, mixed wood residues	BC1&ML 2017 BC1&ML 2040 HH3&HH 2040	Feedstock Production Emissions to Air Model (FPEAM)	Emissions per ton, emissions compared (as ratios) to emissions in the National Emissions Inventory
10	Biodiversity	Presence of avian species (grassland, forest, or generalist species), species richness, habitat area (range) of avian species	Conterminous United States	Switchgrass, miscanthus, energy cane, pine, poplar, willow, eucalyptus, sorghum, corn, soybean, wheat	BC1 2040, reference 2014	Species distribution model, Bio-EST <sup>b</sup>	Percentage of counties occupied by grassland birds and forest birds, species richness
11	Biodiversity	Species among taxa of concern categories: rare native species, keystone species that have a disproportionately large impact relative to abundance, bioindicator taxa that monitor the condition of the environment, species of commercial value, species of cultural importance or species of recreational value	Conterminous United States	Logging residue, whole trees (clearcuts and thinnings)	ML 2017 ML 2040 HH 2040	Habitat suitability framework	Harvest acres, qualitative analysis of habitat suitability at ecoregion scales

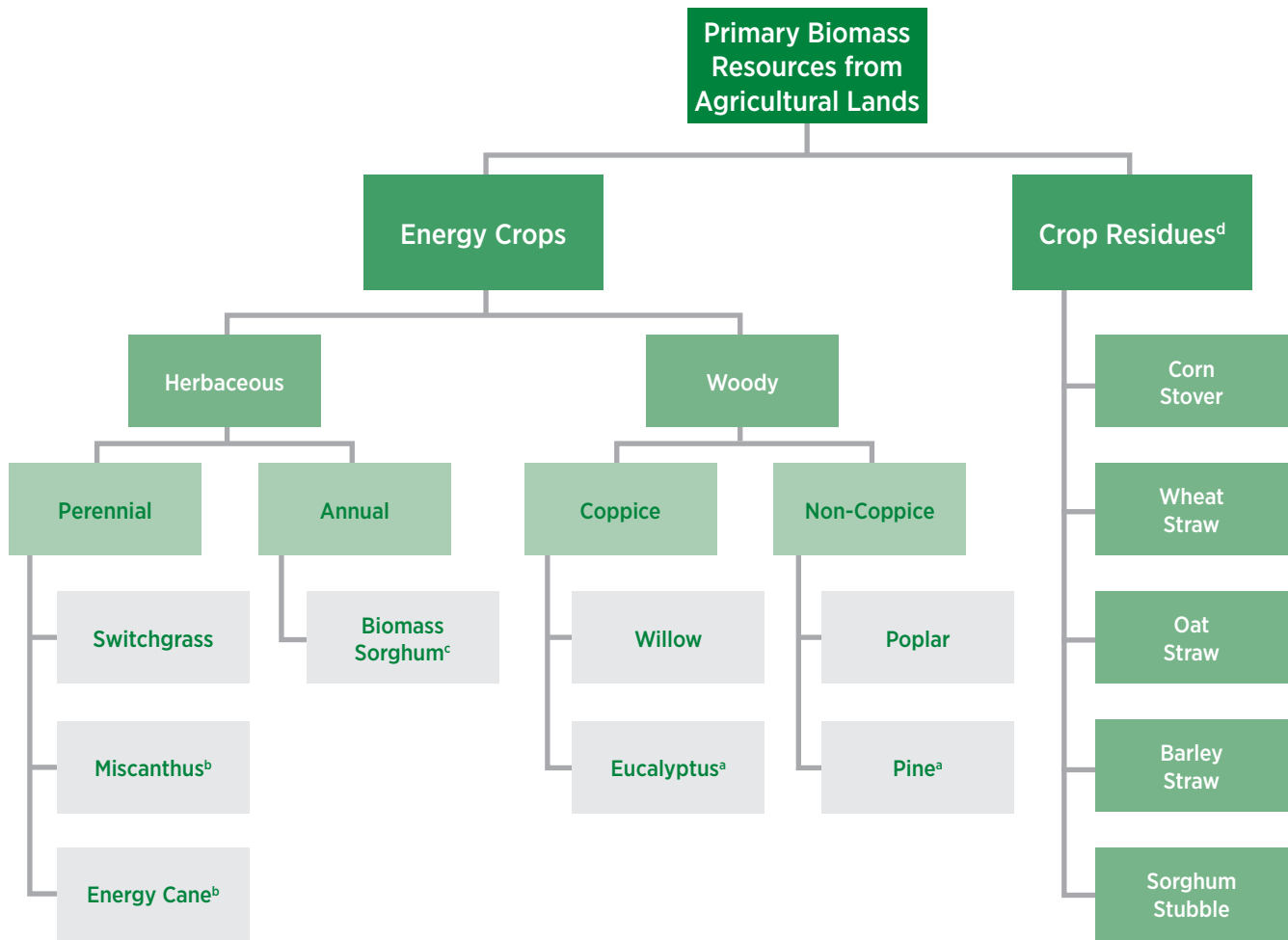
<sup>a</sup> Chapter includes appendix that discusses soil organic carbon changes that could result from biomass harvest in forests.

<sup>b</sup> Bio-EST – Bioenergy-biodiversity Estimation modeling framework

**Abbreviations:** Mg C/ha/yr – megagrams of carbon per hectare per year; g CO<sub>2</sub>e/dt – grams of carbon dioxide equivalent per dry ton; kg/ha – kilogram per hectare; t/ha – ton per hectare; mm – millimeter; gal/yr – gallons per year; gal/month – gallons per month; gal/acre – gallons per acre



**Figure 1.1** | Agricultural feedstocks considered in volume 1 of *BT16*, subsets of which are considered in analyses in volume 2



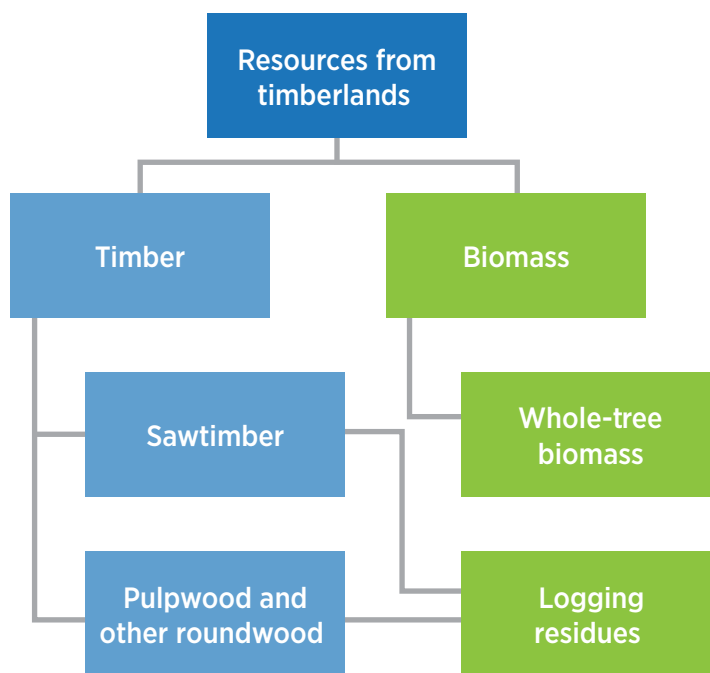
<sup>a</sup> Eucalyptus and pine are newly added feedstocks. They were generalized in the 2011 *BT2* as 8-year rotation, short-rotation woody crops under single-stem management.

<sup>b</sup> Energy cane and miscanthus are newly added feedstocks to the Billion-Ton reporting. They were generalized in the 2011 *BT2* as perennial grasses, along with switchgrass.

<sup>c</sup> The 2011 *BT2* discussed several types of sorghum. For the purposes of this report, “biomass sorghum” depicts any variety developed for high biomass yields, and neither for grain nor sugar content. Budgets for biomass sorghum can represent biomass sorghum, forage sorghum, or sweet sorghum. Modeled yields represent either biomass or forage sorghum; the variety with the highest productivity in a certain region was used.

<sup>d</sup> Agricultural resources already used for biofuels or bioenergy, such as sugar cane bagasse, are reported in volume 1, chapter 2.

**Figure 1.2** | Forest feedstocks considered in volume 1 of *BT16*, subsets of which are considered in analyses in volume 2



The extent of analysis in volume 1 is the conterminous United States. Hawaii and Alaska were not included because of a lack of commodity crop data and scarce Forest Inventory Analysis data to support modeling. Most environmental analyses are performed at a national (conterminous United States) extent, with the exception of the water quality analysis for agriculture, which includes case studies focused on the Iowa River Basin and the Arkansas-White-Red Basin. As with volume 1, most analyses and reporting of results are at the county scale. Exceptions include watershed-level analyses for water quality and quantity.

## 1.5 Supply Constraints in *BT16* volume 1

Several supply constraints designed to reflect guiding principles that account for environmental and socioeconomic considerations were employed in *BT16* volume 1 as well as the 2011 *BT2*. These principles are

consistent with DOE’s mission to develop biomass as a sustainable resource, and with other research that applies environmental constraints to resource analysis (Schubert et al. 2009; Beringer, Lucht, and Schaphoff 2011). These constraints (summarized in fig. 1.3 and explained further in chapter 2) were carefully chosen to reflect practices that are commonly used in the industry or likely to be adopted in the future. Some of these practices are regulated while others are common industry practices with widespread compliance. Simulations are intended to fulfill projected needs for food, feed, forage, and fiber production, and some constraints are implemented to avoid production on lands with high ecological value.

When deciding which supply constraints to impose in *BT16* volume 1, it was deemed impractical and unrealistic to generate supply projections that are not technically feasible (e.g., removing all residue and debris) or cannot be sustained in the long term (e.g., harvesting residues at levels that exacerbate

soil erosion). Using the potential biomass estimates from *BT16* volume 1 means that the same supply constraints are adopted in volume 2, but it is critical to recognize that the environmental effects results are contingent on these constraints. *BT16* volume 2 does not represent the full range of possible environmental effects of potential biomass in the United States; should biomass production practices not follow these modeled supply constraints (for example, using extensive irrigation in the western United States), there

would likely be more adverse environmental effects. Analyzing the full range of worst- and best-case scenarios is outside the scope of volume 2. The potential biomass quantified in volume 1 represents a potential future that enables new insights into the environmental effects of biomass production. *BT16* volume 2 analyses will help determine whether the supply constraints applied in volume 1 are sufficient to protect many aspects of the environment or whether adverse effects remain and additional safeguards are needed.

**Figure 1.3** | Supply constraints employed in *BT16* volume 1 and adopted in *BT16* volume 2

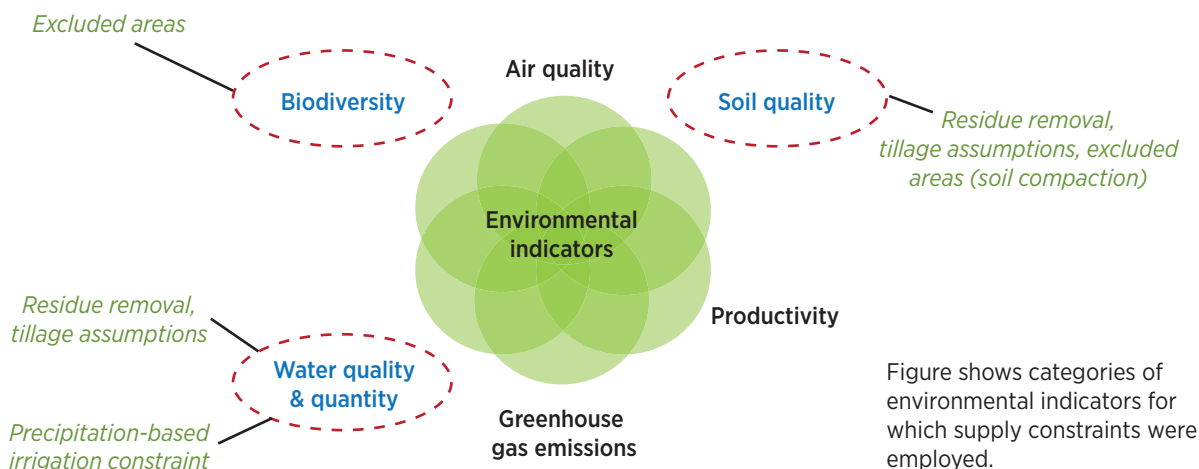


Figure shows categories of environmental indicators for which supply constraints were employed.

## 1.6 Limitations

Many types of environmental effects are not included in this initial environmental analysis of select *BT16* scenarios. For example, the scenario comparisons do not include an estimate of ecosystem-productivity changes or aquatic-biodiversity changes. In addition, many soil-quality effects (e.g., soil nitrogen, phosphorus, and bulk density) are not modeled. Peak-flow and base-flow indicators of water quantity are discussed but not estimated, and water yield for agriculture is not investigated in detail. The biodiversity analysis addresses select taxa in select regions

or ecosystems. The potential for indirect LUC effects nationally and internationally from potential biomass expansion is not quantified in this volume, though issues and definitions are discussed. Environmental indicators for algae biomass for the scenarios in *BT16* volume 1 are not quantified, with the exception of water consumption estimates, but many types of environmental effects are addressed qualitatively. While some aspects of possible economic and social effects are mentioned, *BT16* volume 2 does not investigate these types of potential effects.

Efforts were made to coordinate the various analyses in *BT16* volume 2 to achieve consistency across sce-

narios and assumptions; however, this initial environmental effects analysis for a Billion-Ton report does not fully integrate results across categories, agriculture, or forestry. Further integration in future Billion-Ton reports will enable more robust understanding of the quantitative relationships—the synergies and trade-offs—between different types of potential environmental effects of biomass production.

## 1.7 *BT16* volume 2 Organization

The majority of chapters in this second volume of *BT16* investigate environmental effects of potential agricultural and forest biomass produced in select 2017 and 2040 scenarios simulated in volume 1 (chapters 4–11). Chapter 2 describes the methodology used in volume 1 to estimate potential biomass supplies and summarizes the scenarios used in volume 2. Chapter 3 provides information to help readers interpret biomass supply results from *BT16* related to LUC (land management). Chapter 4 estimates fossil energy consumption and GHG emissions associated with producing biomass and considers the contribution of changes in soil carbon as a result of producing agricultural biomass on land that was previously in other states or under different management practic-

es prior to production of biomass. Chapters 5 and 6 investigate effects on water quality, i.e., nutrient and sediment loadings associated with agricultural and forestry biomass production, respectively. Chapter 7 evaluates the potential effects of forest biomass harvesting on water yields, and chapter 8 examines the water footprint of agricultural and forest biomass as well as the interplay between feedstock mix and water use. Chapter 9 investigates air pollutant emissions associated with agricultural and forest biomass production and how the spatial distribution of air emissions could potentially impact local air quality. To investigate possible effects on biodiversity, chapters 10 and 11 consider habitat-related responses of select wildlife taxa to potential agricultural and forestry biomass production. Chapter 12 provides a qualitative assessment of environmental effects of microalgae in the context of scenarios in which algae production is co-located with CO<sub>2</sub> sources and that waste CO<sub>2</sub> is used for algae production. Chapter 13 evaluates the sensitivity of potential future biomass productivity to climate. Finally, chapter 14 summarizes and interprets results of previous chapters and explores strategies that could be used to enhance environmental outcomes of biomass production. These include strategies identified in this volume and strategies that are employed or under development elsewhere.



## 1.8 References

- Beringer, Tim, Wolfgang Lucht, and Sibyll Schaphoff. 2011. “Bioenergy production potential of global biomass plantations under environmental and agricultural constraints.” *GCB Bioenergy* 3 (4):299–312. doi:[10.1111/j.1757-1707.2010.01088.x](https://doi.org/10.1111/j.1757-1707.2010.01088.x).
- CSBP (Council on Sustainable Biomass Production). 2012. *Standard for Sustainable Production of Agricultural Biomass*, Version 1.0. <http://web.ornl.gov/sci/ees/cbes/News/Final%20CSBP%20Standard%2020120612.pdf>.
- Dale, Virginia H., Rebecca A. Efroymsen, Keith L. Kline, Matthew H. Langholtz, Paul N. Leiby, Gbadebo A. Oladosu, Maggie R. Davis, Mark E. Downing, and Michael R. Hilliard. 2013. “Indicators for assessing socioeconomic sustainability of bioenergy systems: A short list of practical measures.” *Ecological Indicators* 26:87–102. doi:[10.1016/j.ecolind.2012.10.014](https://doi.org/10.1016/j.ecolind.2012.10.014).
- DOE (U.S. Department of Energy). 2016. Bioenergy Technologies Office Multi-Year Program Plan. U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy. <http://energy.gov/eere/bioenergy/downloads/bioenergy-technologies-office-multi-year-program-plan-march-2016>.
- DOE (U.S. Department of Energy). 2011. *U.S. Billion-Ton Update: Biomass Supply for a Bioenergy and Bio-products Industry*. Oak Ridge, TN: Oak Ridge National Laboratory. ORNL/TM-2011/224. [https://www1.eere.energy.gov/bioenergy/pdfs/billion\\_ton\\_update.pdf](https://www1.eere.energy.gov/bioenergy/pdfs/billion_ton_update.pdf).
- EPA (U.S. Environmental Protection Agency). 2011. *Biofuels and the Environment: First Triennial Report to Congress*. Washington, DC: Office of Research and Development, National Center for Environmental Assessment. EPA/600/R-10/183F. <https://cfpub.epa.gov/ncea/biofuels/recordisplay.cfm?deid=235881>.
- GBEP (Global Bioenergy Partnership). 2011. *The Global Bioenergy Partnership Sustainability Indicators for Bioenergy*, First edition. Rome, Italy: Food and Agriculture Organization of the United Nations. [http://www.globalbioenergy.org/fileadmin/user\\_upload/gbep/docs/Indicators/The\\_GBEP\\_Sustainability\\_Indicators\\_for\\_Bioenergy\\_FINAL.pdf](http://www.globalbioenergy.org/fileadmin/user_upload/gbep/docs/Indicators/The_GBEP_Sustainability_Indicators_for_Bioenergy_FINAL.pdf).
- Efroymsen, Rebecca A., and Virginia H. Dale. 2015. “Environmental indicators for sustainable production of algal biofuels.” *Ecological Indicators* 49:1–13. doi:[10.1016/j.ecolind.2014.09.028](https://doi.org/10.1016/j.ecolind.2014.09.028).
- Efroymsen, Rebecca A., Virginia H. Dale, Keith L. Kline, Allen C. McBride, Jeffrey M. Bielicki, Raymond L. Smith, Esther S. Parish, Peter E. Schweizer, and Denice M. Shaw. 2013. “Environmental Indicators of Biofuel Sustainability: What About Context?” *Environmental Management* 51 (2):291–306. doi:[10.1007/s00267-012-9907-5](https://doi.org/10.1007/s00267-012-9907-5).
- Hecht, Alan D., Denice Shaw, Randy Bruins, Virginia Dale, Keith Kline, and Alice Chen. 2009. “Good policy follows good science: using criteria and indicators for assessing sustainable biofuel production.” *Ecotoxicology* 18 (1):1–4. doi:[10.1007/s10646-008-0293-y](https://doi.org/10.1007/s10646-008-0293-y).
- McBride, Allen C., Virginia H. Dale, Latha M. Baskaran, Mark E. Downing, Laurence M. Eaton, Rebecca A. Efroymsen, Charles T. Garten Jr., Keith L. Kline, Henriette I. Jager, Patrick J. Mulholland, Esther S. Parish, Peter E. Schweizer, and John M. Storey. 2011. “Indicators to support environmental sustainability of bioenergy systems.” *Ecological Indicators* 11 (5):1277–89. doi:[10.1016/j.ecolind.2011.01.010](https://doi.org/10.1016/j.ecolind.2011.01.010).

- Perlack, Robert D., Lynn L. Wright, Anthony F. Turhollow, Robin L. Graham, Bryce J. Stokes, and Donald C. Erbach. 2005. *Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply*. Oak Ridge, TN: Oak Ridge National Laboratory. DOE/GO-102005-2135. ORNL/TM-2005/66. [https://www1.eere.energy.gov/bioenergy/pdfs/final\\_billionton\\_vision\\_report2.pdf](https://www1.eere.energy.gov/bioenergy/pdfs/final_billionton_vision_report2.pdf).
- Rogers, J. N.; Stokes, B.; Dunn, J. B.; Cai, H.; Wu, M.; Haq, Z.; Baumes, H. “An Assessment of the potential products and economic and environmental impacts resulting from a billion ton bioeconomy.” BioFPR, 2016, doi: 10.1002/bbb.1728
- Roundtable on Sustainable Biomaterials. 2010. *RSB Principles & Criteria for Sustainable Biofuel Production*. RSB-STD-01-001 (Version 2.1). <http://rsb.org/pdfs/standards/11-03-08%20RSB%20PCs%20Version%202.1.pdf>
- Schubert, R., H. J. Schellnhuber, N. Buchmann, A. Epiney, R. Grießhammer, M. Kulesa, D. Messner, S. Rahmstorf, and J. Schmid. 2009. *Future Bioenergy and Sustainable Land Use*. Berlin, Germany: German Advisory Council on Global Change.

This page was intentionally left blank.