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Land Allocation and Management: Understanding Land-Use Change (LUC) Implications under *BT16* Scenarios

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3.1 Introduction

3.1.1 Objectives

The objective of this chapter is to help readers interpret results from the *2016 U.S. Billion-Ton Report* (*BT16*) volume 1 related to the phenomena generally called "land-use change" (LUC) and "indirect land-use change" (ILUC). LUC can be described as a "change in the use or management of land by humans" (ISO 2015; IPCC 2000). However, definitions of LUC have varied widely in the literature (see appendix 3-A). In this chapter, unless specified otherwise, LUC refers to the effects on land that are caused or implied by the biomass production systems simulated in *BT16*. We describe where, how much, and what type of LUC is associated with the simulations.

The following questions and responses illustrate chapter goals and content:

- Why is analysis of LUC included in the *BT16* volume 2?
    - LUC is an important concern that can determine the acceptability of bioenergy, and current U.S. policies call for monitoring and reporting on environmental effects of biofuel pathways inclusive of LUC.
    - LUC effects are far-reaching and can be measured across all environmental indicators (see chapter 1).
- What are the LUC implications of *BT16*?
    - LUC effects associated with any simulation are determined by model input parameters and assumptions, and are distinctive for each scenario.
    - *BT16* scenarios apply constraints that prohibit net change in the total area of major land classes so that the total area and extent of forestland and agricultural land are held constant throughout all simulations and time periods.
    - Because total forest and agriculture land areas remain fixed, the most significant LUC effects relevant for environmental assessment under *BT16* scenarios involve changes in land management practices.
    - Building on continued trends of yield improvement and cropland area reduction, a principal manifestation of LUC is the net reduction in annual crops, which are replaced by idle land and perennial cover within the fixed agricultural area.
    - Under *BT16* scenarios at $60 per dry ton or less, by 2040, the area in perennial cover increases compared to the agricultural baseline in 2015 by
        - 24 million acres under the base case (BC1)
        - 45 million acres under the 3%-yield annual growth case (HH3).
    - Under the same scenarios, the area in annual crops falls compared to the agricultural baseline in 2015 by
        - 34 million acres under the base case (BC1)
        - 55 million acres under the 3%-yield annual growth case (HH3).
    - Approximately 10 million acres allocated to annual crops in the agricultural baseline in 2015, transitions to idle land under the *BT16* scenarios.

- What other LUC issues are relevant to *BT16*?
  - It is essential to understand the differences between studies designed to estimate policy-driven LUC and resource assessments such as *BT16* that examine potential biomass supplies under specified conditions.
  - The assumptions and constraints used in *BT16* illustrate spatially explicit biomass supplies while excluding most potential LUC concerns by design.
  - Estimates of change always depend on the reference case, and in this chapter we consider the BC1 simulation in 2017, and the agricultural baseline (described in volume 1) in 2015, 2017, and 2040, as references.
  - *BT16* does not simulate other references or define a "business as usual" case for 2040. However, other possible reference case considerations are discussed in appendix 3-A.
  - Replicable methods to measure land-related effects are essential for science-based analysis of biomass production systems.
  - Further research is required to clarify LUC effects of U.S. biomass production systems under different supply, demand, and policy scenarios.

3.1.2 The Importance of LUC and Related Indicators

LUC is important because all other environmental indicators, many of which are addressed in this report, as well as social and economic indicators, can be impacted by LUC (McBride et al. 2011; Dale et al. 2013). Under the Renewable Fuel Standard, LUC and indirect effects caused by U.S. biofuel policy must be considered. Since 2008, the effects of LUC have dominated discussion of environmental impacts of bioenergy because of their implications for greenhouse gas (GHG) emissions, biodiversity, food security, and other aspects of the environment.

The scientific literature identifies two LUC-related issues of high concern: (1) potential loss of areas of high conservation value, such as forests, peatland, wetlands, and native prairies; and (2) potential loss of agricultural output or displacement of cropland. The first type of potential LUC has implications for biodiversity, GHG emissions, carbon stocks and sequestration rates, and other environmental indicators, as discussed in this volume. The second type of potential impact has implications for food security, as discussed in the literature (e.g., GFMG 2010; Durham, Davies, and Bhattacharyya 2012; IFPRI 2015; Kline et al. 2016), as well as indirect effects. Chapter 2 discusses how *BT16* applies modeling assumptions and constraints designed to estimate potential U.S. biomass supplies while controlling for and mitigating these two specific concerns. In this chapter, we focus on LUC implications of the land management practices assumed in association with *BT16* scenarios. As discussed in other chapters, changes in crop type and management are expected to affect most environmental indicators and especially those for soil carbon, GHG and air emissions, water quality, and biodiversity.

3.2 Research Goals Guide Choices for Model Parameters, Assumptions, and Definitions

Different land input parameters and assumptions are applied to answer different questions about land and bioenergy (Dale and Kline 2013a). Many studies have aimed to address questions about the potential effects of a defined biofuel policy on land use (e.g., Fritsche and Wiegmann 2011; Fritsche, Sims, and Monti 2010; Oladosu et al. 2012; Oladosu and Kline 2013; Plevin et al. 2015; Valin et al. 2015; Taheripour and Tyner 2013; Tyner et al. 2010). LUC estimates under specified scenarios require assumptions about relationships among productivity, prices, different commodity markets, and land (characterized by types, costs, locations, ownership, markets, etc.). LUC modeling studies are based on the assumption that biomass production will displace other production or other specific land uses.

3.2.1 The Differences between *BT16* and Analyses that Focus on LUC

BT16 is not an LUC study. Rather, *BT16* describes domestic biomass resource potential with specific limitations on displacing other production (see detailed discussion in section 3.4 below). *BT16* addresses questions about the locations and types of potential biomass within fixed agricultural and forestland areas and under scenarios that provide supplies not only for biomass, but for other projected agricultural and forestry market demands. *BT16* scenarios are neutral about end use (i.e., the potential biomass supplies could be used for any purpose) and biofuel or other policies. While existing policies are implicitly reflected in the USDA baseline projections (USDA 2015a), the U.S. Forest Products Module of the Global Forest Products Model (see chapter 2), and the *BT16* agricultural baselines developed for *BT16* scenarios (see chapter 2), *BT16* supply simulations aim to illustrate prospective sources of biomass independent of any particular bioenergy policy.

BT16 aims to estimate how much biomass could be supplied from current agriculture and forestland in the conterminous United States under supply constraints that limit typical LUC concerns, such as the loss of forests due to cropland expansion. U.S. forestland area and U.S. cropland area are held constant in all scenarios. No land is allowed to transition from forestland to cropland under the simulations. Furthermore, all USDA Conservation Reserve Program (CRP) lands are excluded from biomass production (see *BT16* volume 1, chapter 4). Assumptions and constraints applied in *BT16* scenarios mitigate potential market-mediated, global LUC effects, such as potential impacts on forests outside the United States (see chapter 2), and determine land allocation among crops and land cover. Understanding how these model specifications influence land allocation is relevant for LUC estimates and for the interpretation of environmental effects. In summary, the *BT16* scenarios illustrate future biomass potential from the agricultural and forestland bases as of 2015 and hold those areas constant for each simulation through 2040.

3.2.2 Concepts and Definitions Relevant to LUC

The state of the art for LUC analysis reflects both operational and conceptual limitations associated with terms, definitions, and associated land classifications used for analysis. Operationally, key terms used widely in the LUC and ILUC literature are often poorly defined, as many have acknowledged in the literature (e.g., Dale and Kline 2013a; ISO 2015; Kline, Oladosu, et al. 2011; Valin et al. 2015; Warner et al. 2014). Conceptually, LUC estimates from models are limited by reliance on assumptions ranging from initial land classifications and attributes (including exclusivity of “use”) to the assumed causal drivers for transitions between classes (Efroymson et al. 2016). Large uncertainties in basic land cover classifications are well documented (e.g., Congalton et al. 2014; Kline, Parish, et al. 2011; Feddema et al. 2005; Emery et al. 2017). The classification uncertainties increase when land “use” is inferred from land cover classes (Lambin, Geist, and Lepers 2003), and uncertainties are inherently far greater still whenever an analysis attempts to quantify “change” (O’Hare et al. 2010; Dale and Kline 2013a; Dunn et al. 2017). Even more controversial are assumptions about causal drivers of LUC, such as the interaction of temporary price changes in commodity markets with many other known causal factors of deforestation (Efroymson et al. 2016; Aoun, Gabrielle, and Gagnepain 2013; Kline et al. 2016).

Text Box 3.1 | *BT16* Land Terms and Major Crops Relevant to LUC

Key terms are defined in the glossary. The terms “biomass” and “potential biomass supply” are used without assumptions about end use. This is in contrast to many biofuel LUC assessments that estimate effects of a policy or production level specified for bioenergy. In this chapter, the term “bioenergy” is used in examples that aim to make the discussion relevant to U.S. Department of Energy Bioenergy Technologies Office stakeholders. Moreover, scenarios in 2040 involve biomass “energy crops,” so named because they are likely to be used for energy purposes.

Agricultural land can be classified as annual crops versus perennial cover, or as biomass (energy) crops versus traditional (commodity) crops. For our calculations of change in land cover and management, idle land and Conservation Reserve Program (see glossary) lands are excluded. Traditional crops, such as corn and wheat, can supply stover or straw (biomass); however, these are not energy crops as defined by the U.S. Department of Agriculture (USDA) because their primary end uses are not for bioenergy. Agriculture simulations are based on the Policy Analysis System model (see chapter 2) using the following USDA major crops (parenthetical values next to each crop indicate millions of acres in 2015, the initial simulation year of the agricultural baseline): corn (88), soybeans (84), hay (58), wheat (all types, 56), cotton (10), grain sorghum (7), barley (3), oats (3), and rice (3). Forest-sector simulations are based on the Forest Sustainable and Economic Analysis Model (see chapter 2) to estimate potential supplies based on timberlands in the United States.

Every analysis that attempts to consider LUC is a product of underlying input data and assumptions, including how land classes and land use are defined (Dale and Kline 2013a; Woods et al. 2015). *BT16* is no exception, although the goal of volume 1 was to estimate potential sustainable supplies rather than to perform an LUC analysis. *BT16* focuses on biomass potential within the major land classes—agriculture and forestry—in the United States and builds on the best available USDA data sets for these two sectors. *BT16* biomass potential is estimated under constraints that do not permit net changes in the land base over time for primary uses (e.g., forest to cropland) but rather involve changes in specified management over time on existing agriculture and forest domains. This makes *BT16* distinct from other studies that attempt to define and parameterize land classes and to differentiate the services provided to society over space and time according to the classification system utilized. Models attempting to estimate LUC simplify data out of necessity, for example, by aggregating dynamic, heterogeneous uses into single classes for analysis (e.g., crop, pasture, forest, or urban). Relying on simplified land classes to assess LUC and generalizing characteristics of each class can be misleading and detracts from science-based assessment and communication of verifiable impacts.

3.2.3 LUC and Biomass from Forestland

See chapter 2 for a description of methods and assumptions applied to estimate potential biomass supplies from the forestry sector. The potential for the most significant LUC drivers associated with forestry biomass (e.g., loss of natural forest) is excluded from *BT16* by design because the Forest Sustainable and Economic Analysis Model (1) aims to assure that demands for conventional wood products were met, in addition to those for biomass; (2) assumes no changes in areas for total timberland, plantations, and natural forest management lands; and (3) incorporates supply constraints reflecting considerations, such as no new road building and limits or exclusions for biomass removals depending on terrain slope. As with agriculture lands, if less-restrictive assumptions are applied, larger potential biomass supplies could be simulated, but additional environmental issues would also be expected to arise.

Furthermore, *BT16* does not consider the fact that some historic cropland is in transition to become forest due to afforestation incentives provided under the CRP and similar programs. Because *BT16* scenarios aim for supply potential that reflects some sustainability principles, all CRP lands were reserved and excluded from consideration in scenarios.

Thus, the estimates of biomass from the forestry sector are meant to be conservative and avoid significant LUC concerns. Potential effects of alternative forest management approaches on the existing forestland, (e.g., water quality, habitat for selected species) are discussed in other chapters of *BT16* volume 2. The remainder of this chapter focuses on the changes simulated on agriculture land.

One LUC effect relevant to forest cover is the increasing use of cropland for short-rotation woody crops (SRWCs). For the purposes of this analysis, these are treated as changes in management practices on existing agricultural lands because, after a short rotation, the lands could rotate back into other agricultural uses. For example, as shown in table 3.1, by 2040 in HH3 case, 11 million acres of cropland are planted in SRWCs that can be coppiced (e.g., willow, eucalyptus), and an additional 13 million acres of cropland are planted in other SRWCs (e.g., poplar, pine). These changes in land management are discussed separately as one type of LUC within the agriculture sector.

3.3 Indicators to Capture LUC Effects

To understand environmental effects of biomass production on land, clearly defined indicators and units are required to characterize and measure changes over space and time (McBride et al. 2011). The broad definition of LUC is nearly impossible to apply with consistency because any action or inaction of humans that potentially impacts land could be described as LUC. Furthermore, major changes in land qualities can occur within a forest or agriculture landscape without reaching a specified threshold for a defined change in cover class (a common proxy for LUC in modeling), such as forest/pasture or pasture/cropland. Therefore, specific indicators that permit consistent measurement of pertinent characteristics (i.e., of effects that stakeholders care about) are essential. Examples of indicators relevant to LUC include carbon stocks and net primary productivity or biomass yield. While these are not measures of LUC per se, they are examples of indicators that capture the effects of different land management practices and production systems. Soil carbon is discussed in chapter 4. This chapter reviews how the amount of land managed for annual crops, pasture, and other perennial crops varies under different scenarios.

Two important conclusions about the use of LUC information to estimate environmental effects can be drawn from extensive literature and field work (e.g., Gasparatos et al. 2017): (1) what matters is what really changes rather than general land labels used for land classification, and (2) different management practices within a defined land class can lead to significant changes over time in measured values for environmental indicators (e.g., carbon stocks, biodiversity, water quality). For example, Fargione et al. (2008) illustrate how the estimation of effects of bioenergy on carbon stocks depends on many factors independent of the basic land class used for LUC assessment. Forests range from degraded woodlands in dry environments to old-growth tropical forests. Carbon stocks and accumulation rates can vary by orders of magnitude while the land remains labeled as “forest.” The same holds true in agricultural systems where, in addition to soils, weather, and prior use, the carbon stocks and sequestration rates depend on factors such as the type, timing and frequency of site preparation, fertilization, harvest, and soil tillage (e.g., specific equipment used, type and depth of tillage, area disturbed).

Biomass supplies in *BT16* are sourced from the utilization of residues and coproducts from forestry and agriculture (e.g., timber thinning, corn stover), which are recognized in the literature to involve negligible potential for direct or indirect LUC (e.g., Fargione et al. 2008); biomass supplies in *BT16* are also sourced through modifications of agricultural management practices, which influence environmental indicators over time. The incremental increases in biomass production under *BT16* complement rather than displace current production. The assumptions and approach underlying *BT16* reflect historical U.S. trends to improve land management efficiency in response to new and increasing biomass production. From 1984–2011, for example, agricultural output increased by 1.5% per year while total area of land used for agriculture decreased by more than 0.5% per year, on average (Wang et al. 2015).

LUC-related effects that are estimated using indicators are a product of comparing *BT16* scenarios (BC1 in 2017 and 2040 and HH3 in 2040) to each other and to the agricultural baseline in 2015, 2017, and 2040. Estimated effects always depend on the reference case, and many alternative future scenarios are possible (appendix 3-A). While *BT16* scenarios exclude LUC between forestry and agriculture uses by design, and also exclude the use of CRP land for biomass crops, the scenarios involve changes in land management, crop type, and crop acreages within specific portions of the remaining agricultural landscape. The magnitude and implications of these changes are discussed below.

3.4 LUC and Agricultural Land: Cropland and Pasture

The allocation of land among agricultural uses, including conventional crops, energy crops, and perennial cover, is presented in table 3.1.

Table 3.1 | Crop Type, Cover Classification (Annual, Perennial, Idle), and Total Area in the Agricultural Baseline and in the *BT16* Scenarios Considered in Volume 2

		Agricultural Baseline 2015	Agricultural Baseline 2017	BC1 2017	Agricultural Baseline 2040	BC1 2040	HH3 2040
Crop	Cover Class	Millions of Acres					
Barley	Annual	3.5	3.2	3.2	2.9	2.8	2.7
Corn	Annual	88	90	90	89	85	74
Cotton	Annual	9.8	9.8	9.8	11	8.6	7.7
Oats	Annual	3.0	2.5	2.5	2.4	2.1	1.9
Rice	Annual	2.9	2.9	2.9	3.1	3.0	2.8
Sorghum	Annual	7.5	7.4	7.4	7.0	6.2	5.8
Soybeans	Annual	84	78	78	77	66	60
Wheat	Annual	56	53	53	54	46	42
Total Major Crops		**255**	**246**	**246**	**246**	**219**	**197**
Hay	Perennial	58	57	57	57	56	56
Idle	Idle	13	22	22	23	23	23
Subtotal other cropland (idle, hay)		71	79	79	80	79	79
Total Cropland excl. energy crops		**326**	**326**	**326**	**326**	**298**	**277**
Total Pasture excl. energy crops		**446**	**446**	**446**	**446**	**409**	**407**
Bio-sorghum	Annual					1.7	2.3
Coppice wood	Perennial					5.0	11
Energy cane	Perennial					0.0	0.3
Miscanthus	Perennial					21	37
Non-coppice	Perennial					9.3	13
Switchgrass	Perennial					28	24
Total Energy Crops		**0**	**0**	**0**	**0**	**64**	**88**
	Perennial	504	504	504	504	528	549
	Annual	255	246	246	245	221	200
	Idle	13	22	22	23	23	23
Total Agricultural Land Considered in *BT16*		**772**	**772**	**772**	**772**	**772**	**772**

		Agricultural Baseline 2015	Agricultural Baseline 2017	BC1 2017	Agricultural Baseline 2040	BC1 2040	HH3 2040
Crop	**Cover Class**	**Millions of Acres**					
Additional U.S. Agricultural Land:							
Reserved CRP	Idle	*27*	*27*	*27*	*27*	*27*	*27*
Other farmland (woodlands, built up, roads, waste land, other)		*110*	*110*	*110*	*110*	*110*	*110*
Total farmland incl. CRP reserve		**909**	**909**	**909**	**909**	**909**	**909**

Table 3.1 summarizes total land allocation by class for the agricultural baseline in 2015, 2017, and 2040 to allow comparison with allocations under the *BT16* scenarios analyzed in this volume. The land allocation data are consistent with U.S. farmland classifications as defined by the USDA National Agricultural Statistics Service (NASS) (USDA NASS 2014) and as reported in the USDA baseline projections (USDA 2015a), with pasture categories combined in table 3.1. For comparison, note that the most recent Census of Agriculture (USDA NASS 2014) identified 914 million acres of total farmland, with 390 million in cropland (includes irrigated and cropland pasture); 415 million in other permanent pasture and range; 77 million in woodlands and grazed woodlands; and another 33 million acres in built-up areas, wasteland, or other non-productive uses of farmland. The smaller area considered in *BT16* compared to the total USDA census (USDA NASS 2014) reflects reductions in cropland area based on the USDA baseline projections (USDA 2015a) and the exclusion of farmland outside the conterminous United States in *BT16*. The bottom rows of table 3.1 illustrate that 137 million acres were excluded from consideration in *BT16* simulations before the analysis began to apply constraints: 27 million acres of cropland in CRP were excluded, along with 110 million acres in built-up areas, wasteland, or other non-productive uses of farmland.

The differences in land allocation and management observed under different years and scenarios in table 3.1 include (1) increases in idle cropland area in all scenarios compared to the agricultural baseline in 2015; (2) decreases in conventional crop area in all scenarios compared to 2015; (3) decreases in pastureland area in 2040 *BT16* biomass scenarios compared to other scenarios; and (4) net increases in perennial land cover under *BT16* biomass scenarios in 2040.

Idle cropland includes land allowed to go fallow for a period as part of normal rotations with other crops, as well as land available to support crops in response to market signals (see glossary). Because we do not assume idle cropland is managed exclusively as perennial or annual cover, idle remains a separate land class. For *BT16* scenarios, 27 million acres of CRP are held constant and excluded from eligibility for any other use. By USDA's definition, CRP falls into the "idle cropland" class. Thus, including the reserved CRP lands, there would be 50 million acres of idle cropland in the 2040 scenarios. LUC-related issues associated with different types of agricultural land management are discussed below.

3.4.1 Changes in Agricultural Land Management under *BT16* Scenarios

The primary types of LUC associated with *BT16* supply scenarios involve changes in land management practices on land that has been in use for conventional crops and pasture. The most significant net LUC from 2017 to 2040 is the transition from conventional annual crops to perennial land management systems, a transition that accelerates with increasing demand for biomass. The area estimated to be managed as perennial cover in 2040 is 45 million acres greater under the HH3 scenario than the area of perennial cover in the 2015 agricultural baseline or the 2040 agricultural baseline (see chapter 2) without new biomass demand. The geospatial distribution of the net change from annual to perennial cover is illustrated in figure 3.1 for BC1 2040 (reflecting a 24 million–acre expansion) and figure 3.2 for HH3 2040. The darker colors in figures 3.1 and 3.2 represent counties where perennial cover increased by 25%–40%. The light grey shading over most counties in the United States indicates that change was negligible or small (less than +/-5%). No counties have loss of perennial cover greater than 5% in 2040 under *BT16* scenarios. Larger increases in percentage of perennial cover occur on agriculture land in areas where simulated returns from conventional crops are not as competitive with energy crops under the conditions defined in the base case scenario, BC1 2040.

The total land in perennial cover is about the same in the following scenarios: the agricultural baseline in 2015 and in 2017, the BC1 scenario in 2017, and the agricultural baseline in 2040 (table 3.1). However, as with other land categories, while the total area in a class may appear to be constant across the nation over several years, this lack of net change can mask significant shifts in locations of perennial cover as well as net changes in any given county. In general, we observe that perennial cover increases incrementally in response to assumed biomass markets under *BT16* scenarios.

The net expansion of perennial cover is significant in terms of land area (i.e., 24 to 45 million acres) but modest when considered relative to the overall agricultural landscape considered in the scenarios (772 million acres), as shown in figure 3.3. The expansion of idle cropland as a separate category in each scenario relative to the 2015 agricultural baseline is also illustrated in figure 3.3.

Figure 3.3 illustrates how total agricultural area managed as annual crops is estimated to decline and transition to perennial cover when the allocation of land in the agricultural baseline in 2015 is compared to land allocations in 2040 under (1) the agricultural baseline projection to 2040 without biomass demand; (2) BC1; and (3) HH3. Figure 3.3 illustrates the progressively increasing amounts of land that transition on net from annual crops to perennial cover under these scenarios. The figure also illustrates that these shifts are small relative to the total agriculture land area considered in the analyses (772 million acres). Finally, note that in addition to the 27 million acres of CRP land reserved outside the analysis, the simulations include 23 million acres of idle land in each future scenario. The idle land provides a potential cushion, allowing response to unexpected increases in demand for crops or biomass in other sectors.

Figure 3.1 | Geospatial distribution of changes in perennial cover under the base case (BC1) scenario[1]

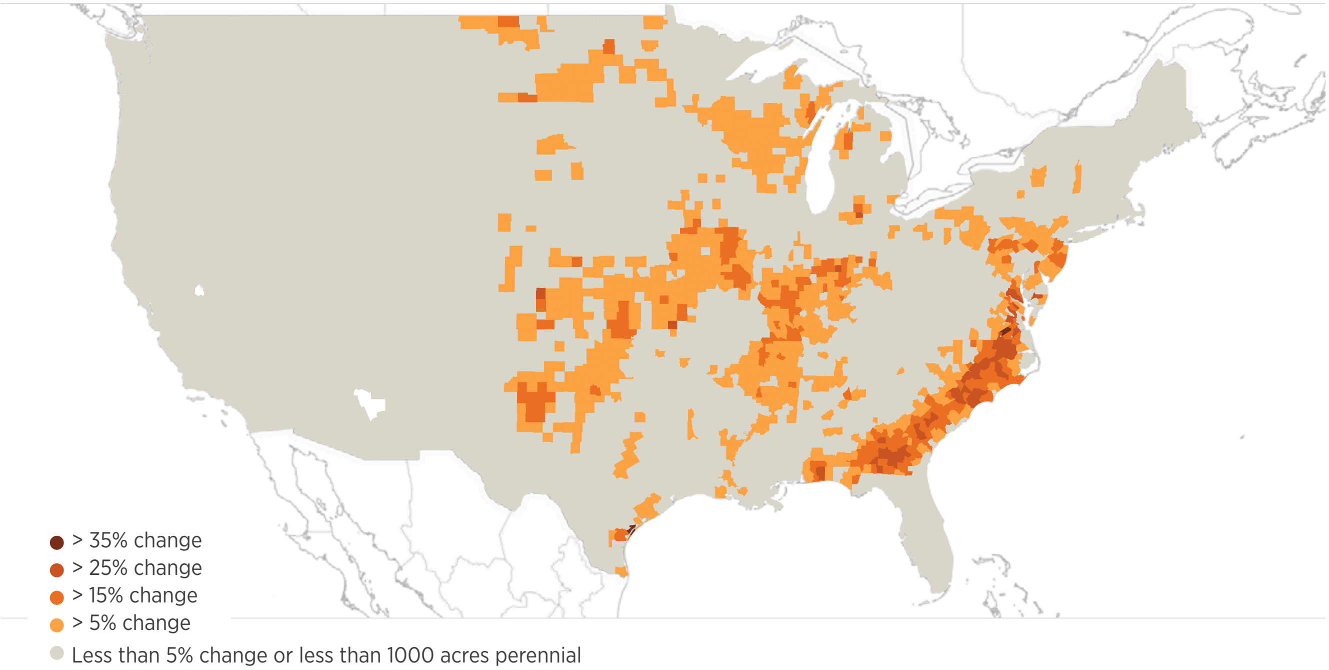
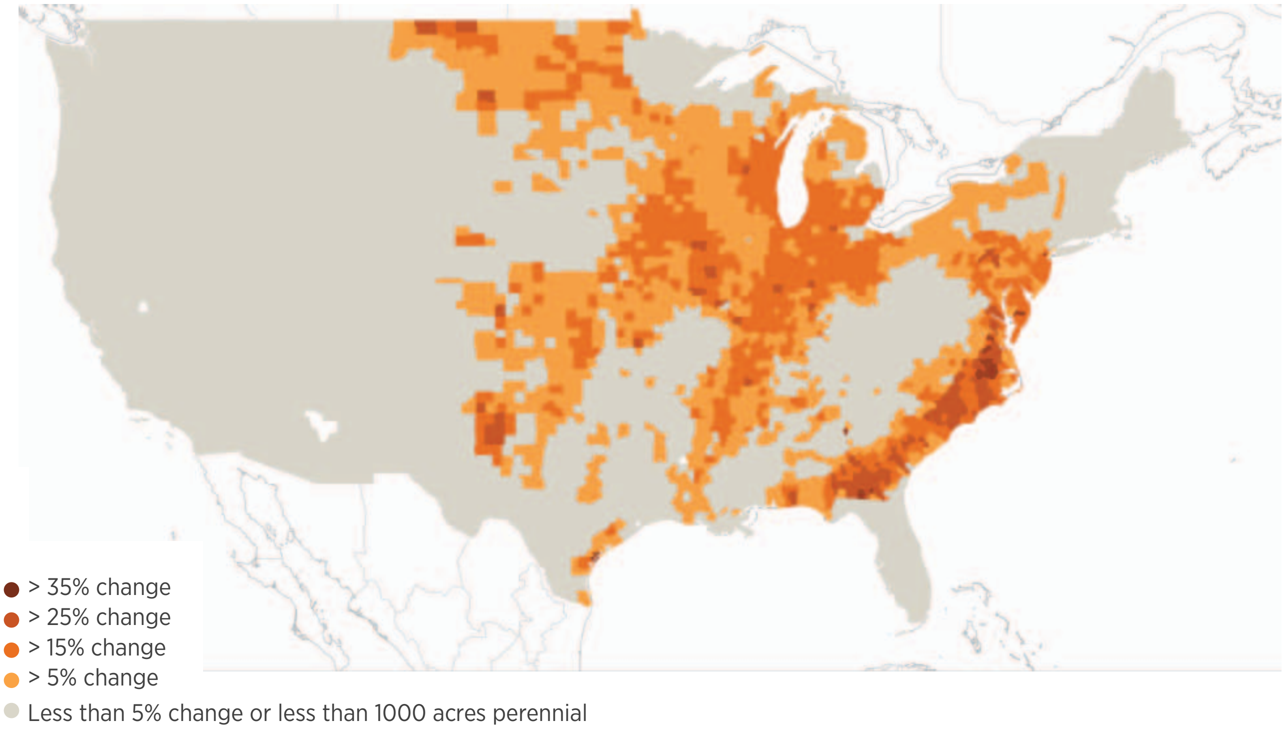
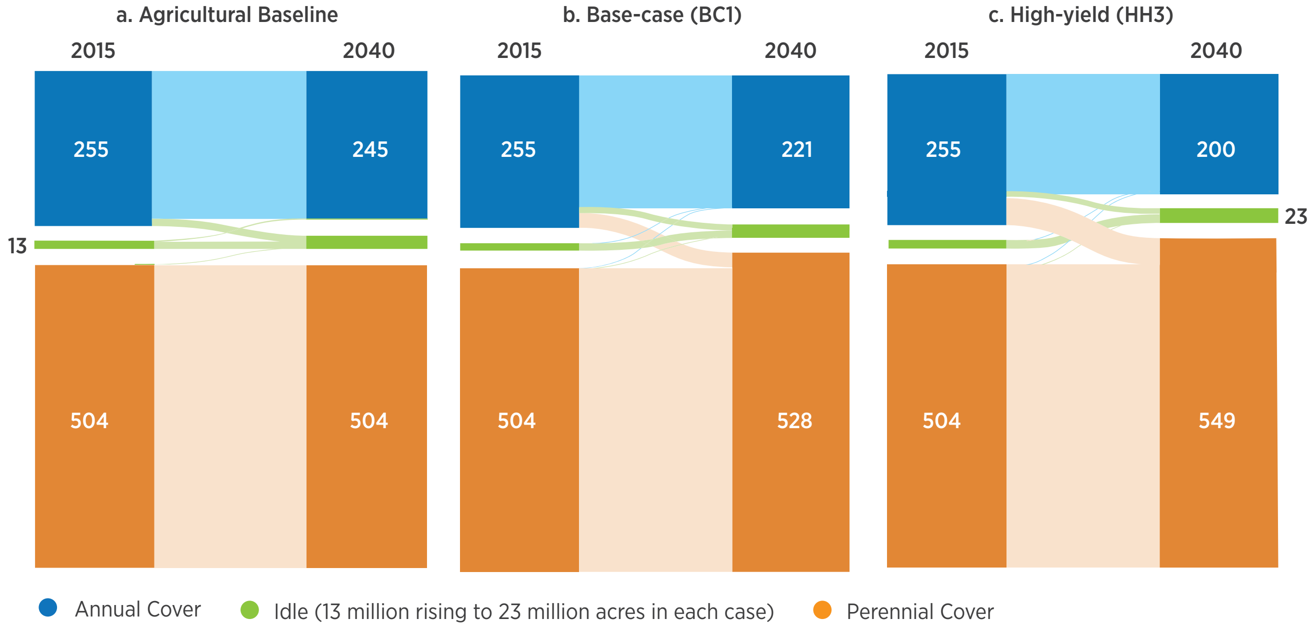


Figure 3.2 | Geospatial distribution of changes in perennial cover under the 3% annual yield increase (HH3) scenario[1]



[1] Change in perennial cover by county is the difference between the percentage of total agricultural acres (cropland + pasture) managed as perennial cover in *BT16* 2040 scenarios (BC1 or HH3) and the percentage managed as perennial cover in the 2040 agricultural baseline without new biomass production. In each scenario, the gray includes a few counties that transitioned to less than 1,000 acres of perennials in 2040. These are mostly urban areas and average less than 265 acres of planted perennials per county. For instance, this filter avoids showing Clayton County, Georgia, in the >35% change category, even though it went from 0 to 44 perennial acres out of a total of 106 planted acres.

Figure 3.3 | Agricultural land (millions of acres) managed as annual crops, perennial cover, or idle cropland in 2015 and 2040 as estimated under (a) the agricultural baseline; (b) base case scenario (BC1); and (c) high-yield scenario (HH3)



In addition to the gradual transition from row crops to perennial biomass crops illustrated in figure 3.1, changes in management occur on pasture. By 2040, 37–39 million acres, or about 8% of total pasture area in the 2015 extended agricultural baseline, would undergo changes in management to produce energy crops. This area is not segregated in figures 3.1–3.3, which compare annual crops to perennial cover, because both pastureland and the energy crops illustrated are classified as perennial cover.

The changes from annual to perennial land management affect 3% of total agricultural land under BC1 and about 6% under HH3, and the transitions occur gradually between 2015 and 2040. There are also gradual changes in the management of pastures, with about 8% of total pastureland area in the 2015 agricultural baseline shifting to management for energy crops by 2040. Fencing and pasture rotation are management practices that are assumed to intensify production on another 56–58 million acres of pasture (13% of total pastureland) to maintain forage output in tandem with increasing energy crop production. Percentages here are expressed relative to the total areas of cropland and pastureland in the 2015 agricultural baseline and the projected agricultural baseline in 2040 (table 3.1). As with any model, input parameters and assumptions regarding land classes, land area available for different uses, and productivity influence how land is allocated among traditional and energy crops over time. Assumed increases over time in the productivity of pasture (see *BT16* volume 1, section 4.8.5), yields for conventional and energy crops, and simulated prices of biomass are the drivers for the modeling results allowing for increased biomass feedstock production within the current (2015) agricultural landscape.

3.4.2 Land Input Assumptions Drive LUC Estimates

The input values for land parameters and constraints relevant to LUC are described in chapter 2. Key parameters impacting LUC include the initial land base and land classes considered, and the annual rates of expansion allowed. For example, energy crop acreage in a county is limited to 5% of permanent pasture, 20% of cropland pasture, and 10% of cropland. These percentages reflect an estimate of barriers and opportunities associated with the adoption of new crops.

Before applying any constraints, an initial agricultural land base of 772 million acres was considered for *BT16* biomass supply scenarios modeled in the Policy Analysis System (POLYSYS) (table 3.1). This acreage includes eight major row crops plus cultivated hay on cropland, for a total of 313 million acres of cropland, plus 446 million acres of pasture. For *BT16*, pastureland includes 11 million acres classified as cropland pasture, plus other pasture and rangeland (figure 3.4). The definition of each class is based on the USDA 2012 Census of Agriculture (USDA NASS 2014; see glossary for full definitions), and the acreages in table 3.1 for cropland classes were based on average values reported over 4 years in recent NASS statistics (see appendix C of *BT16* volume 1).

When interpreting any description of LUC, it is essential to understand that "change" is always expressed with respect to the comparison of two selected values. Thus, LUC associated with *BT16* varies depending on whether it is a product of comparing a given simulation (1) to another simulation (e.g., BC1 2040 versus HH3 2040), (2) to the agricultural baseline in 2015 or 2040 (table 3.2), (3) to different years within a given scenario (e.g., BC1 2017 versus BC1 2040), or (4) to some other reference case. Changes occur in the USDA baseline projections (USDA 2015a) and in the projected agricultural baseline simulated in POLYSYS, independent of assumed new biomass demand. For example, in the agricultural baseline scenario, the area planted in major crops is estimated to decrease by about 10 million acres while overall outputs increase through improved productivity.

In *BT16* biomass scenarios, the area of agricultural land managed for annual crops in BC1 2040 is 25 million acres less that the quantity simulated in BC1 2017; and from BC1 2017 to HH3 2040, the decline is 46 million acres. Similar differences are observed if BC1 2040 and HH3 2040 are compared to the agricultural baseline in 2040 (table 3.1). However, the reduction in land area managed for annual crops is different if these scenarios are compared to the 2015 agricultural baseline (table 3.2), due primarily to decreased demand for commodity crops between 2015 and 2017. Most reductions in annual crop acreage over time can be accounted for by increased yields and decreased area planted in conventional crops (primarily soy beans, corn, and wheat; see table 3.1). As the area managed for conventional annual crops declines, the area managed as perennial cover increases along with increasing energy crop production.

Table 3.2 highlights the net changes in land managed as annual crops, idle, and perennial cover when the 2015 agricultural baseline is compared to scenarios for 2040. Table 3.3 shows the allocation of 2015 cropland acres to specific biomass crops in 2040 under the two scenarios (BC1 and HH3). Table 3.4 illustrates the allocation of 2015 pastureland to biomass crops under the two scenarios.

Table 3.2 | Total Agricultural Land Allocation by Scenario and Class: Annual Crop, Perennial Cover, or Idle Cropland (millions of acres). Differences in 2040 Compared to the 2015 Agricultural Baseline Are Noted in Parentheses. (The sum of some columns is affected by rounding.)

Land Type	Agricultural Baseline 2015	Agricultural Baseline 2040	*BT16* BC1 2040	*BT16* HH3 2040
Millions of Acres				
Total land in annual crops	255	245 **(-10)**	221 **(-34)**	200 **(-55)**
Perennial cover	504	504	528 **(+24)**	549 **(+45)**
Idle cropland[a]	13	23 **(+10)**	23 **(+10)**	23 **(+10)**
Total	**772**	**772**	**772**	**772**

[a] Does not include CRP lands.

Table 3.3 | Land Allocation by Crop Type: Energy Crops on Cropland (millions of acres)

Crop Type and Land Cover Classification	BC1 2040	HH3 2040
Biomass sorghum	2	2
Total annually cultivated biomass crops	**2**	**2**
Switchgrass on cropland	7	8
Non-coppice SRWCs on cropland	5	9
Coppice SRWCs on cropland	2	8
Miscanthus on cropland	11	21
Energy cane on cropland	0	0
Total perennial biomass crops	**25**	**47**

Table 3.4 | Land Allocation by Crop Type: Energy Crops on Pasture Including Cropland Pasture (millions of acres)

Crop	BC1 2040	HH3 2040
Switchgrass	21	15
Non-coppice SRWCs	4	4
Coppice SRWCs	3	3
Miscanthus	10	16
Energy cane	0	0
Total	**37**	**39**

3.4.3 Agricultural Land Allocated to Biomass Crops

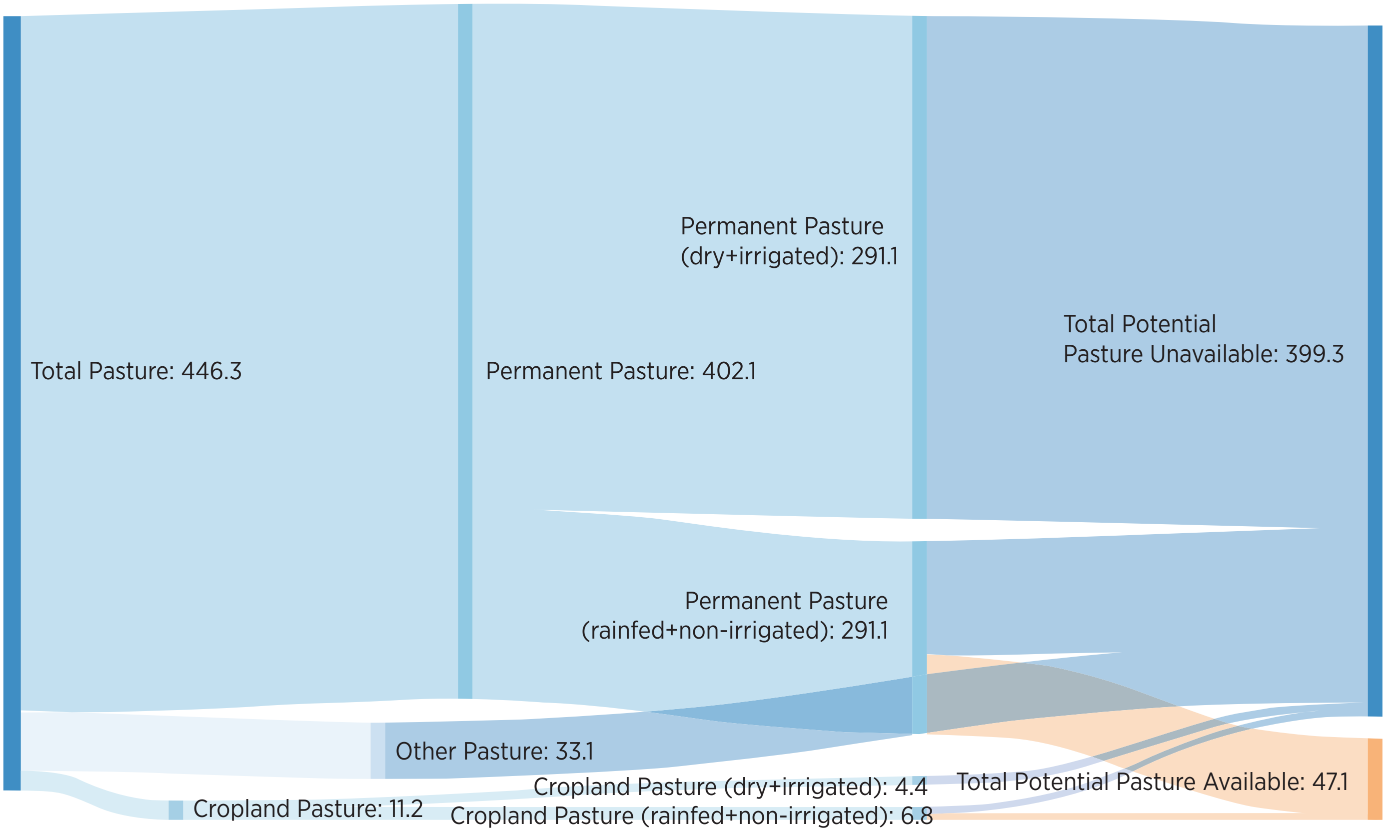
After all constraints used for *BT16* simulations are in place, the total agricultural land area considered within the POLYSYS model runs (e.g., land "eligible" for potential energy crop production) is about 243 million acres (196 million cropland + 47 million pastureland). The POLYSYS simulations considered the competitiveness of energy crops compared to other potential crops on only this subset (31%) of the initial agricultural land base of 772 million acres. Recall that the 772 million–acre initial land base already excluded 137 million acres of farmland, including CRP, from the analysis (table 3.1). Under the biomass scenarios discussed in this volume, 64 million acres (BC1) or 88 million acres (HH3) are allocated to be managed as energy crops by 2040, representing 8% (BC1) or 11% (HH3) of the initial land base, respectively, and about one-third of the area identified as being potentially eligible for energy crops under the constraints and assumptions used for *BT16* simulations.

In conclusion, the energy crop land allocation in 2040 (64 or 88 million acres for BC1 and HH3 scenarios, respectively) represents less than 10% of total private farmland in the conterminous United States (USDA 2014). Under *BT16* scenarios, yield improvements and pasture intensification gradually allow for increasing quantities of biomass production without significantly displacing output required to meet future projected demand in other sectors. These results reflect assumptions for crop yield improvements that meet future demands for food, feed, and fiber on less land, and are consistent with a continuation of historical agricultural land productivity trends (Wang et al. 2015).

3.4.3.1 LUC Implications of BT16 Constraints for Energy Crops on Pastureland

In addition to the limit on annual rates of expansion in *BT16* scenarios, energy crops are not allowed on irrigated pasture, as this is assumed to be retained to supply specialized local markets. Likewise, energy crops are excluded from dry rangelands or pasture with less than 25 inches of precipitation per year. The constraints for rain-fed pastureland reduce the area eligible for planting energy crops in any year to a defined land base of 118 million acres (see *BT16* volume 1, appendix C, figure C-2). Further constraints are applied such that in any one county, energy crops may not exceed 40% of the eligible land for pasture over the simulation period (i.e., 2017–2040) because of the requirement for management-intensive grazing to maintain forage output (*BT16* volume 1, appendix C). When all constraints are applied to the baseline pasture area of 446 million acres, the maximum eligible pastureland for energy crops represents about 47 million acres, or 11% of total pastureland, as shown in figure 3.4. Assumptions regarding pasture management intensification to meet projected future demand for forage (see chapter 2) have implications for modeling results.

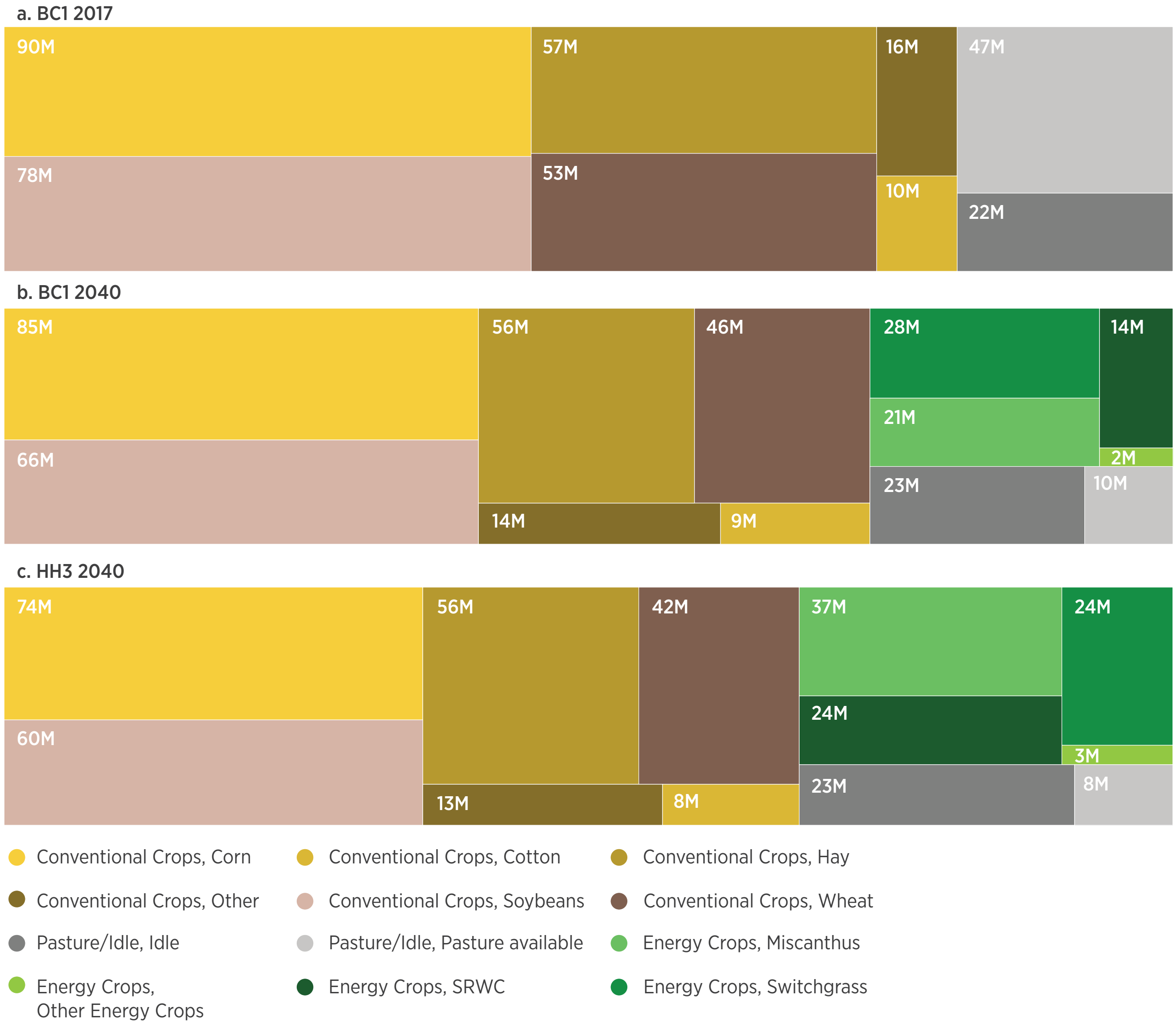
Figure 3.4 | Total U.S. pastureland area and subset eligible for biomass crops (millions of acres). The constraints applied in BT16 reduce the area of pasture eligible for energy crops from a total of 446 million acres to 47 million acres (applicable to all scenarios, in all years).



3.4.3.2 Energy Crops on Cropland

The cumulative effect of the *BT16* constraints for expansion of energy crops is that the maximum amount of cropland potentially eligible for energy crops by 2040 represents about half of the cropland area considered in the 2015 agricultural baseline and in BC1 2017. The cumulative expansion in 2040 of 27 million acres of energy crops in BC1 represents only about 8% of total 2015 cropland area (326 million acres) and 15% of the eligible cropland area under the constraints used in *BT16* (27 million acres out of 181 million eligible). The high-yield scenario (HH3) results in a cumulative planting of energy crops by 2040 on 49 million acres of cropland, or about 15% of the 2015 agricultural baseline cropland area. As illustrated in figure 3.5, the allocation of cropland to row crops declines over time in *BT16* scenarios in association with increasing biomass production. A gradual reduction in U.S. cropland area is consistent with historic trends and with the agricultural baseline projection that simulated a 10 million–acre reduction in cropland area from 2015 to 2017 (table 3.2). In part, the reduced area of cropland reflects the fact that total factor productivity of U.S. agriculture has been increasing while land as an input has been declining (Wang et al. 2015).

Figure 3.5 | Allocation of cropland (326 million acres) and pastureland potentially eligible for energy crops (47 million acres) under BT16 simulations (millions of acres): (a) BC1 2017; (b) BC1 2040; and (c) HH3 2040. Each Figure (a–c) represents allocations across 373 million acres.



3.5 LUC Modeling

Models are used to estimate LUC by comparing areas for a defined land class (e.g., forest or agriculture) under two simulations. If assessing effects of bioenergy policy, LUC studies typically involve one simulation in which biofuel production increases and a reference case in which it does not. The differences in the area of each land class that are generated by these two scenarios are presented as LUC.

In most studies, the model outputs do not distinguish between direct and indirect LUC (Valin et al. 2015; Dale and Kline 2013b), but these labels are sometimes applied. Differentiation of ILUC from direct LUC is typically based on assumptions about the baseline or reference land use and system boundaries.

For example, in the case of economic models examining U.S. biofuel policies, LUC that occurs outside the United States is commonly labeled "indirect." However, a study focusing on biomass production in a single U.S. state may consider LUC projected outside of that particular state to be indirect. Other studies attempt to allocate land areas based on an assumed initial land cover compared with a simulated land cover, wherein any land used for biomass production that is modeled to occur on non-agricultural land is considered a "direct LUC," and the sum of all other changes in land use is assumed to be indirect.

The potential global impacts of an expansion of biomass production in the United States depend on many factors not analyzed under *BT16* scenarios. Reasonable assumptions about increasing biomass production could generate estimates that vary widely not only in terms of magnitude, but also in terms of direction of the effects—particularly in terms of whether forestland is expected to expand or contract in response to policies associated with biomass production (see appendix 3-A; Kline et al. 2009).

3.5.1 How *BT16* Relates to Concerns about ILUC

BT16 is not designed to address questions about LUC, but understanding how bioenergy policies actually interact with other policies, markets, and disturbances (such as fire) is critical for more accurate LUC assessment (Kline and Dale 2008). A review of the conceptual basis for LUC modeling can illustrate how common concerns about indirect effects are managed in *BT16* with a focus on ILUC modeling. The two main forces assumed to drive ILUC are (1) price mechanisms and (2) crop displacement:

- Under the price mechanism, ILUC can occur if (1) biomass production causes higher prices for other commodities; (2) these higher prices are transmitted to markets in other countries; and (3) the response in those countries to the higher prices is to clear more land for growing those crops than would have been cleared otherwise.
- Under the displacement mechanism, ILUC can occur if (1) biomass production displaces local output of a crop; (2) the reduced output of the crop is replaced by growing more of the crop elsewhere; and (3) growing more of the crop elsewhere requires the clearing of new agricultural land.

Both of these mechanisms require causal pathways (a ➔ b ➔ c…) in which the absence of any one step would block the effect (Efroymson et al. 2016). For example, under the first mechanism, if higher prices are not transmitted to other nations, or if higher prices cause intensification rather than new land clearing, then the pathway is interrupted and the assumed effect would be blocked. Empirical evidence suggests that such conditions may create breaks in the causal chain assumed for the price mechanism. Rather than testing for the existence of these mechanisms, economic models for ILUC typically begin by assuming the mechanisms are in place and then seek to assess effects of a "shock" in biofuel demand to generate ILUC estimates.

Regarding the two basic mechanisms above, *BT16* constraints were applied to minimize these "market-mediated" effects. For the price mechanism, it is estimated under the *BT16* supply scenarios that commodity prices could be higher or lower depending on the rate of yield growth assumed (see *BT16* volume 1, appendix C). Regardless of whether prices are projected to decline or rise, the price changes associated with biomass production are small relative to other drivers of change in food commodity prices (Kline et al. 2016). More detailed analysis of the impacts of potentially higher or lower prices (depending on the *BT16* scenario) on global markets and land use is beyond the scope of the analysis for this study.

Regarding potential crop displacement mechanisms, *BT16* simulations were based on scenarios that allowed conventional commodity outputs to increase over time and fulfill increasing demand. The assumed incremental expansion of energy crops in tandem with increasing productivity reduces potential mechanisms theorized to cause ILUC. Under the HH3 scenario, in which energy crops occupy the greatest area (88 million acres) by 2040, the land in row crops is simulated to decline by 56 million acres while total output continues to grow each year to meet or exceed demands projected under the 2040 agricultural baseline (see *BT16* volume 1, appendix C). While corn stover is an important source of biomass in BC1 and HH3 simulations, acreage in corn and conventional crops overall decline in biomass production scenarios. These *BT16* results are consistent with decadal trends, which show a small but steady reduction in conventional crop acreage over time. This study focuses on potential new cellulosic biomass supplies building from a 2015 agricultural baseline; it does not consider changes to current conventional biofuel programs (e.g., corn starch ethanol and soy-based biodiesel production).

The *BT16* constraints aim to avoid biomass production locations, management practices, and economic competitions that would represent likely environmental concerns (see chapters 1 and 2). This approach is consistent with other studies that investigate options to produce biomass while preventing or mitigating LUC and other environmental impacts (e.g., Brinkman et al. 2015; RSB 2015; Gerssen-Gondelach et al. 2016; Gerssen-Gondelach, Wicke, and Faaij 2015; Beringer, Lucht, and Schaphoff 2011; Schubert et al. 2009; Wicke et al. 2015). The assumptions applied to estimate potential biomass supplies that could be produced from current agricultural and forestlands without changing the areas now used for those broad categories are likely to be as accurate as (if not better than) alternative assumptions that attempt to predict how these land areas will change in the future (e.g., see Buchholz et al. 2014). Even though no one expects all current forestland acres to remain the same over the next 25 years, the *BT16* assumption that net area does not change is defensible given the purpose of the assessment and historical trends (discussed below). No net change in area is a common *ceteris paribus* (all else held constant) modeling assumption that facilitates simulations by avoiding additional complications. Furthermore, the U.S. Renewable Fuel Standard (H.R. 6 2007) only considers biomass used for fuels to be renewable if it is derived from land cleared or cultivated for agriculture or managed forests prior to 2007. For more discussion of the assumptions underlying the agricultural baseline and how *BT16* scenarios address projected future demand, see chapter 2 of *BT16* volume 2 and appendix C of *BT16* volume 1.

3.5.2 *BT16* Results in Context of Other LUC Studies

It is difficult to compare the *BT16* resource assessment to other studies designed to estimate LUC, as the questions asked and approaches applied are distinct. However, it can be enlightening to carefully review the input parameters and assumptions underlying each approach to determine what is driving the results of a given simulation of future biomass production. Assumptions and details behind *BT16* are carefully documented to support transparent analysis (see chapter 2).

Input data sets and assumptions are critical factors that determine LUC assessment results. The land class ontology, land areas and uses considered, and land rents assumed in a baseline are key factors, along with how spatially explicit land units are defined and how they are segregated or aggregated for analysis. These input specifications vary widely from study to study and are one of many sources of divergent LUC estimates. Further, the criteria and data used to differentiate land cover from land use, and to specify past productivity and potential future productivities at high resolution (not to mention current carbon stocks and rates of net sequestration or emissions), are rarely documented but are also critical to many LUC effects assessments.

Modelers acknowledge that ILUC estimates cannot be validated (NRC 2011; Valin et al. 2015; Babcock 2009). Calibrating estimates of ILUC attributed to biomass production is challenging because (1) the LUC is not defined in practical, consistent, and verifiable terms; (2) other confounding factors determine if and when observable changes, such as deforestation, occur around the world; (3) the processes involved are not singular events but rather reflect constant and ongoing incremental changes and dynamic cycles; and (4) to calibrate and validate models would require extensive and costly field analysis to support statistical analyses of all potential factors and support a defensible allocation of observed changes among countless causal agents (Efroymson et al. 2016; Valin et al. 2015; Kline et al. 2009). Even if all the data and statistical analyses could be completed, a reference case must be simulated in order to estimate "change," and therefore, modeling assumptions are a necessity (NRC 2011).

Given high uncertainty and limitations of LUC models (Plevin et al. 2015; Verburg, Neumann, and Nol 2011; Aoun, Gabrielle, and Gagnepain 2013; Souza et al. 2015; Hertel et al. 2010; NRC 2014), it is important to examine underlying assumptions and input variables that drive LUC results for any study in order to understand and interpret results. Indeed, many assumptions used in past LUC modeling for bioenergy have been found to be invalid (e.g., Babcock 2009; Kim and Dale 2011; Kline, Oladosu, et al. 2011; Dale and Kline 2013a), and there is little empirical evidence to support the types and magnitudes of LUC that have been projected (Langeveld et al. 2014; Babcock and Iqbal 2014; Oladosu et al. 2011). Recent research suggests that the state of science is inadequate to include ILUC in international standards (Zilberman et. al., 2010; ISO 2015; ASTM 2016). As stated in a policy analysis report by the National Research Council, the "range of estimates for GHG emissions from indirect land-use changes is wide…," but "GHG emissions from land-use changes cannot be ignored…results by definition carry the assumptions and inherent uncertainties in these models"; the report concludes that "[a]dditional research is needed to better understand the socioeconomic processes of land-use change and to integrate that process understanding into models" (NRC 2011). The caveat to carefully examine input specifications and assumptions is applicable to any analysis attempting to estimate impacts of future or alternative land management, including *BT16*. Comparing input data and assumptions helps put land allocations from *BT16* scenarios into a broader context of LUC analysis. See appendix 3-A for further discussion.

Estimating future LUC is difficult in part because of the controversies that surround analysis of past LUC. For example, some analyses begin by assuming that land in cropland subcategories—such as idle, hay, and cropland-pasture—are "non-agricultural" grassland in the baseline. It is then not surprising that these analyses identify large amounts of "grassland conversion" (e.g., Mladenoff et al. 2016; Wright and Wimberly 2013). However, based on USDA definitions, acres that such studies flag as "converted" are more accurately described as forming part of ongoing management and rotations on cropland because these lands were previously used and classified as cultivated cropland (USDA NASS 2014; Kline, Singh, and Dale 2013; Qin et al. 2016; Johnston 2014). Further, managing idle, hay, and cropland-pasture land subcategories in rotation with row crops may be a preferable strategy to achieve ecosystem benefits (such as soil conservation, reductions in pests and the need for herbicides and pesticides, and soil moisture conservation) and to efficiently achieve other goals within constraints dictated by local circumstances. Regardless, under *BT16*, idle and hay are considered part of the cropland class, which is consistent with USDA definitions.

There is often not a clear line to separate grassland from pasture, or pasture from other cropland (see appendix 3-A). Alternating or coproducing row crops with perennial crops over long rotations is one of the many management complexities that makes analysis of LUC difficult or misleading. Therefore, we recommend focusing on actual management practices and the specific effects of those practices on environmental indicators, rather than vague LUC labels for temporary changes in land management.

3.6 Discussion

In this section, we review how *BT16* simulations compare to historic LUC trends, discuss limitations and uncertainties inherent in LUC analysis, and propose some directions for future research. Because some type of LUC is constantly occurring practically everywhere that humans are present and because LUC involves multiple ongoing interactions rather than a singular event, modeling LUC is a challenge. Therefore, LUC assessments must begin by clearly defining the question to be addressed, the type of LUC of concern, and the data to be used, and then applying an approach appropriate for the situation.

In the case of *BT16*, given the constraints that prohibit net changes in total areas for forest and agriculture (and the reservation of 27 million acres for CRP within the agriculture land base), the LUC issues relate to estimated land management changes and how the management practices and locations associated with biomass production compare to historic land management and alternative future scenarios. Above, we reviewed the *BT16* scenarios compared to projected future baseline scenarios. Below, we consider historical data and trends.

3.6.1 Land for Biomass Crops in Context of Historical Trends

To place the *BT16* land allocations in 2040 scenarios into perspective, consider that over the 30-year period of 1982–2012, U.S. agricultural output increased persistently at an average rate of 1.5% growth per year, while over the same time period, the land used as an input for agricultural production fell at an average rate of 2.7 million acres per year—resulting in an 82 million–acre net reduction (summing cropland, pasture, and range), as shown in figure 3.6 (USDA 2015b). Focusing on the area of cultivated cropland, USDA analysis found that this input to production fell by 66 million acres, from 376.2 million in 1982 to 310.3 million in 2012, as illustrated in figure 3.7.

The ability to increase agricultural output while using less land over the past two decades is largely attributed to “total factor productivity” improvements (figure 3.8; USDA ERS 2016a; Wang et al. 2015). System efficiency can improve by increasing coproducts and reducing wastes. Risks and costs are reduced by diversifying market options and increasing flexibility for substitution.

Future agricultural land-use trends will be influenced by many factors, including the impact of climate change on crop yields (chapter 13), commodity prices, and agricultural policies. Under the *BT16* BC1 scenario, 64 million acres could be dedicated to biomass by 2040. This is similar to the acreage that could shift to non-agricultural uses if historical trends were to continue throughout the simulation period. However, future land-use trends may not follow past trends and are always uncertain. If new technologies and markets create incentives for cover crops, double crops, or higher yields, or if other mechanisms increase land-factor productivity, then less land will be required to meet future demand projections and more land would be available for other uses, including biomass. However, if yields do not grow as assumed in the *BT16* scenarios, or if weather or markets disrupt production, or demands for commodity crops are higher than anticipated, then less land would be available. Thus, while *BT16* simulations appear reasonable and are consistent with long-term historical trends for agricultural land management, actual future land use will be dependent on many factors.

Figure 3.6 | Net change in land cover/use between 1982 and 2012 (thousands of acres) (USDA 2015b)

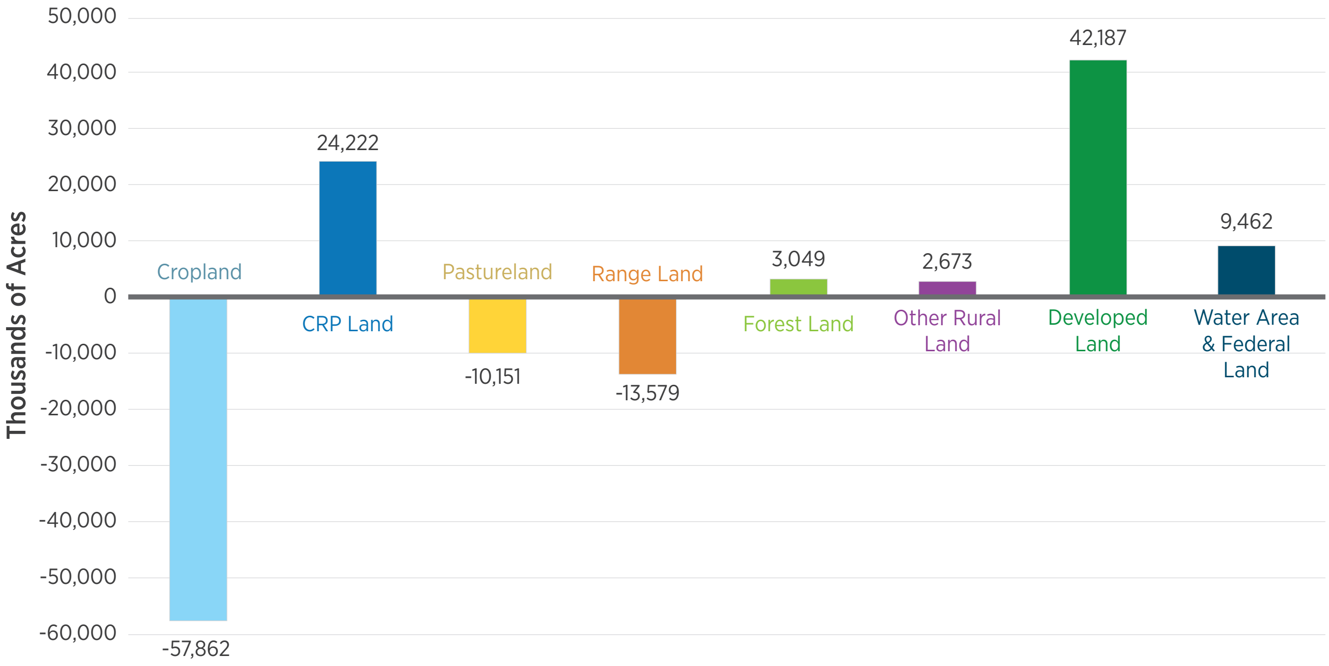


Figure 3.7 | U.S. cropland cultivated and uncultivated, 1982–2012 (USDA 2015b)

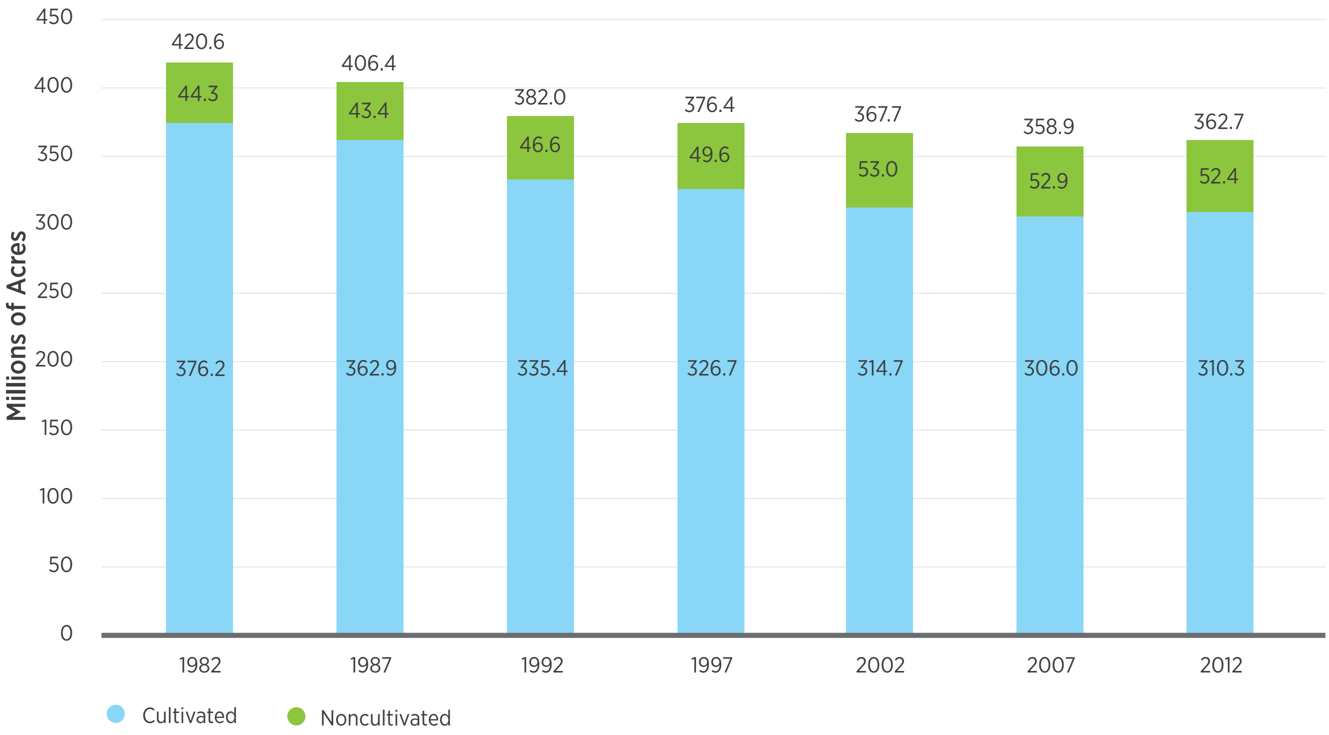
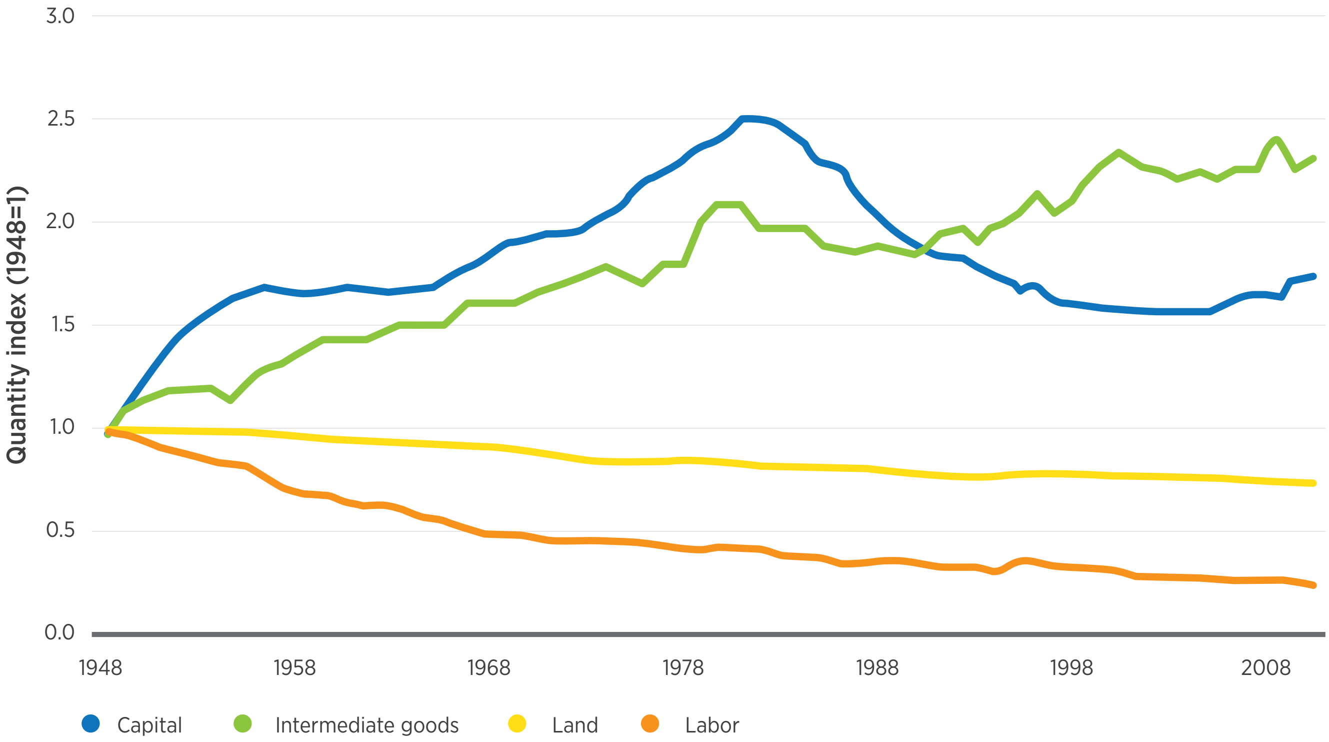


Figure 3.8 | Total factor productivity in U.S. agriculture steadily increased from 1948-2010 while the value of land as an input to production decreased (Figure reproduced from Wang et al., 2015).



3.6.2 Implications and Potential Benefits of *BT16* LUC

Desirable improvements in measured values for environmental indicators—such as air quality, soil carbon, and GHG emissions—are expected when management practices change from input-intensive annual crops to low-input perennial cover crops, SRWCs, and idle land (e.g., Robertson et al. 2008; Dale et al. 2014). Under *BT16* BC1 2040 and HH3 2040 scenarios, these transitions in land management (or LUC) from annual to perennial cover occur on 34 or 45 million acres, respectively. This is the most important type of LUC associated with *BT16* scenarios.

Despite data limitations and uncertainties, evidence from other chapters in this volume and biomass case studies shows that significant environmental improvements can be achieved when agricultural lands are managed for native perennial cover crops rather than annual crops (Dale et al. 2011; Robertson et al. 2008). Perennial crops require lower quantities of pesticides, herbicides, and fertilizers, as well as less mechanized field work, such as spraying, cultivating, and tillage passes (frequency and types of tillage), and less tillage depth (intensities) over time.

The measurement and interpretation of environmental indicators are highly dependent on contextual conditions (Efroymson et al. 2013). The benefits of native perennial cover crops depend largely on two variables: (1) the length of time perennial cover is sustained before soils are again cultivated or disturbed and (2) the alternative land management system in the absence of the perennials. However, net benefits of perennials also depend on additional contextual factors (e.g., soil types, slope, orientation, historical soil management, and crop rotations), management, and weather. Similarly, the effects of biomass crops on lands that were formerly pasture will depend on the types of cover or crops, how land is managed, and what the alternative land cover and management scenario would be in the absence of biomass markets.

To understand the magnitude of benefits that could be derived if 45 million acres of U.S. cropland that were previously managed for row crops were instead managed as perennial cover, consider experiences documented from CRP. The environmental benefits of CRP have been widely acknowledged (e.g., Cowan 2010; Dale et al. 2010; Dale et al. 2014; Herkert 2002; Herkert 2007; Robertson et al. 2008). The extent of CRP enrollment is currently capped by congressional legislation not to exceed 24 million acres (Agricultural Act of 2014, Pub. L. No. 113-79). That is less than the 27 million acres reserved for CRP under all *BT16* simulations. More importantly, it is less than half as large as the net reduction in annual crops simulated in *BT16* HH3 scenario (55 million acres). Therefore, some types of environmental benefits from the biomass production simulated under *BT16* could be estimated to be of similar magnitudes as, cover larger areas than, and be more widely distributed than current CRP, which is assumed to be maintained or allowed to expand somewhat under all scenarios. When land that was previously managed for annual crops becomes managed for perennial energy crops, the expected net effects on the environment depend on several factors, including the prior land conditions, prior land management, the energy crop that is planted, and the management of the energy crop system. Some research suggests that native grasses, such as switchgrass, can increase the abundance of bird species that are conservation priorities (Murray et al. 2003).

Outcomes are more uncertain on pastureland. Beneficial or adverse effects may occur when energy crops are grown on land formerly managed as pasture, depending on many contextual conditions. For example, if the baseline pasture is assumed to be a healthy mixed grassland that is subsequently cultivated and planted with a non-native (exotic), monoculture species such as miscanthus, declines in grassland bird species could occur (see chapter 10). On the other hand, if the baseline pasture is assumed to be poorly managed, over-grazed, or eroded, and subsequent management restores perennial cover with native grasses or SRWCs, there could be significant improvements in soil, water quality, wildlife habitat, and biodiversity. While many potential beneficial environmental effects can be estimated based on the results of *BT16* simulations, the uncertainties and limitations associated with any LUC analysis remain significant.

3.6.3 Uncertainties and Limitations in LUC Assessments

In developing and interpreting LUC assessments, one must gauge what questions are reasonable and useful to ask, balancing research objectives with available data and models. *BT16* was designed to estimate the quantity of economically-viable biomass that could be produced under a set of constraints that are meant to avoid or mitigate many of the potential negative impacts associated with LUC. The analysis is not a prediction of the future, but rather, a spatially explicit illustration of a specific biomass production case.

One advantage to the *BT16* approach is that it reduces some large uncertainties inherent in economic modeling of the LUC effects of energy crops (e.g., Plevin et al. 2015). Some researchers consider the uncertainty in LUC modeling to become unbounded and unknowable when indirect effects are included (O'Hare et al. 2010).

Nonetheless, several areas of uncertainty remain in *BT16* volume 1, and uncertainty is inevitable whenever future events are modeled. Uncertainties in LUC estimates arise from crop management assumptions, reference cases, and land classifications, all of which are discussed in more detail below.

BTI6 assumptions relevant to LUC include the specifications assumed for managing each crop system. The timing and type of land management are critical in determining changes in soil organic carbon, GHG emissions, and other environmental variables over time. Yet, spatially explicit data for management, such as type, depth, and timing of tillage activities, are limited. Agricultural scenario analyses tend to assume simple, single-step transitions from one crop to another crop, rather than the complexity involved in the use of cover crops and long-term rotations (Brankatschk and Finkbeiner 2015) or the highly variable tillage intensities and timing, which necessarily respond to weather conditions. Commodity market fluctuations are normal and also influence management in any given growing season. The uncertainty surrounding these variables increases exponentially as they are projected further into the future. Researchers are still learning about the extensive range of crop rotations and management practices used in U.S. agriculture today (Porter et al. 2016; Porter et al. 2015; James 2016). In the real world, land uses are not exclusive, as is assumed in models. For example, livestock are pastured on cropland after crop harvest. Similar practices can be applied to land managed for biomass. Any single field can provide a mix of products ranging from timber and biomass to fruit, grains, and pasture. When multiple crops and multiple uses are simplified into classes for analysis, LUC estimates may have little relationship to the actual changes in soil and water management on the ground.

Uncertainties are also associated with adoption rates for new crops and technologies. Swinton et al. (2016) found low willingness to bring marginal lands into production for bioenergy crops but generally found a greater willingness to use existing agricultural lands—a finding that is aligned with the assumptions applied in *BTI6* (Swinton et al. 2016; Swinton et al. 2011). However, analysis of these and other socioeconomic factors that influence adoption rates and LUC were not within the scope of this *BTI6* assessment.

Among many challenges associated with the *BTI6* analysis—and, indeed, most analyses that consider U.S. biomass production and LUC—is the lack of data to clearly characterize past land-use history. It is for this reason that the soil organic carbon change analysis (chapter 4) relies on assumptions about land-use history regarding how much time land had spent in cropland and pasture. Historical data for tillage and crop rotations have significant bearing on actual environmental conditions and future outcomes.

3.6.3.1 Reference Case

The reference case is the point of comparison used to estimate change. Reference cases may be called the business-as-usual, extrapolated future, extended baseline, or counterfactual case. Whenever a change is calculated, the point of comparison becomes the reference case. The reference case for most analyses in this volume is the BC1 2017 scenario. However, reviewers concerned about LUC recommended that this chapter consider the agricultural baseline as a reference case, as discussed earlier. Appendix 3-A reviews how different potential reference case assumptions can generate wildly divergent conclusions about the expected LUC associated with a set of well-defined *BTI6* scenarios.

History suggests that changes in the area classified as agriculture or cropland in the future will depend on a mixture of local and national factors, ranging from how ownership changes over time to stock market returns, policies impacting land taxation, farm programs and subsidies, and, particularly, the programs defined under the federal farm bill (i.e., the current 2014 farm bill [Agriculture Act of 2014, Pub. L. No. 113-79]). Farm bill provisions, such as crop insurance, CRP funding, and crop subsidies, have an influence on the U.S. agricultural landscape that appears to be more important than short-term price signals and biofuel markets (Babcock 2009; Kline et al. 2016). For example, despite price spikes in farm commodity prices that began in 2006, USDA acknowledged that “in 2007, total cropland area—which includes cropland used for crops, idled cropland, and cropland used for pasture—reached its lowest level since the Major Land Use series began in 1945” (USDA ERS 2016b).

Similarly, there are uncertainties in assumptions necessary to estimate future pastureland productivity and intensification options under reference scenarios. As with most aspects of modern agricultural production, the relationships between forage yield, stocking rates, management intensification practices, and other markets are far more complex in the real world than in model simulations. Historical trends show increasing livestock production from a decreasing land area, and the majority of U.S. meat now comes primarily from confined animal operations. As grain yields increase and prices stagnate, livestock producers may find it advantageous to continue shifting to supplemental feed as a substitute for grazing. For more details on the uncertainties surrounding pastureland in *BTI6*, see volume 1.

In *BTI6*, the reference system for agriculture is represented by the agricultural baseline (*BTI6* volume 1, appendix C). Because there is a 10 million–acre difference between 2015 and 2017 agricultural baseline scenarios, the net reduction in annual crop acreage under *BTI6* scenarios will depend on which reference case is used. This difference illustrates the importance of clearly specifying the reference case.

Assumptions are necessary to simulate future conditions as a reference point to estimate LUC. If a model assumes that, on the margin, land not required for agriculture returns to forest, that model’s results are distinct from a model that assumes those lands would end up being managed for urban or other developed uses. Thus, the assumptions behind the reference case used in determining LUC are at least equally as important as those governing the biomass case. Yet, there is no agreement on how to best define a reference case for comparison (Soimakallio et al. 2015; Zamagni et al. 2012; Kline, Oladosu, et al. 2011).

There is also little agreement on how the timing of measurements should occur to define “change” and whether change should be simplified to be a single, irreversible event (as is often assumed in models) or to be represented by multiple events, cycles, and transitions that can be reversed (Dale and Kline 2013a). Partly due to these complications, the reference system is not clearly specified in most studies purporting to conduct LUC analysis (Soimakallio et al. 2015; Matthews et al. 2014).

3.6.3.2 Definitions and Data Sources

Differences in LUC estimates and their interpretation also arise when studies rely on different definitions or data sources for basic inputs, such as available agricultural land. For example, confusion is often generated from overlapping land classifications at the cropland-pastureland interface and the USDA definitions associated with pasture and grazing lands that have changed over time (see appendix 3-A). USDA sources for total pasture/rangeland on private property in 2007 ranged from 409 million acres to 529 million acres—a 120 million acre (30%) difference, depending on which source and definitions are used (USDA 2016c; also see table 2 in appendix 3-A). This is one of many reasons why there are large uncertainties when attempting to measure LUC involving cropland and pastureland.

Consider, for example, a 2016 article on LUC associated with biomass in the conterminous United States (i.e., the same area considered in *BTI6*), which began by assuming an agricultural land base of 366 million acres, including both cropland and pasture (Hudiburg et el. 2016). This is less than half of the USDA-defined agricultural land base considered in *BTI6* and helps illustrate how seemingly similar studies can generate divergent results. Different baseline land bases and different assumed land productivities will generate starkly different estimates of LUC associated with the same level of biomass production. Many published analyses of LUC for bioenergy lack a clear exposition of detailed baseline data and specifications for land classes and productivities, making it difficult to interpret and compare the results (Soimakallio et al. 2015).

3.6.3.3 Crop Rotations and Indistinct Lines among Land Classes

Crop rotations matter for LUC estimates because they imply changes in inputs, emissions, soil carbon, water quality, and other variables that depend not only on what is grown in a given year, but also on what was grown in prior years and what will be grown in subsequent years. For convenience, models of LUC omit most complexity of crop rotations. Some models, as in *BTI6*, choose a few representative rotations, such as corn-soy, for the analysis. Ideally, historical crop rotations over a 25-year period should be considered when developing scenarios 25 years into the future. Lacking such data adds uncertainty to LUC assessment and the corresponding estimates of soil organic carbon, GHG, and other factors. When assumptions omit or ignore past practices and crop rotations, the estimates of environmental impacts associated with land management for biomass production can be skewed, misrepresented, or misinterpreted (e.g., see Dunn et al. 2017; Dunn, Mueller, and Eaton 2015; Kline, Singh, and Dale 2013).

When the USDA National Laboratory for Agriculture and Environment (James 2016; Porter et al. 2015) assessed rotations in fields 15 acres or larger in size over a 6-year period (2010–2015) in the Corn Belt, 36,098 unique rotation strings were identified. While most rotations in the Corn Belt involve corn and soy beans, the next most common rotation observed was surprising: 5 years of pasture with 1 year of corn. Indeed, following the different variations of corn-soy rotations, the next six most common unique rotations identified by USDA in the Corn Belt all involved pasture in rotation with other crops. This suggests that a significant share of land classified as pasture is managed in rotation with annual crops. And conversely, a share of annual cropland likely includes forage or pasture rotations. Most LUC studies assume distinct boundaries and inherent differences in soil quality and productivity between pastureland and cropland in the United States. Available data sets such as the USDA "cropland data layer" have limitations when they are used to estimate LUC (Reitsma et al., 2016).

Complex and constantly evolving crop rotations are one of the challenges to conducting meaningful LUC analysis (Brankatschk and Finkbeiner 2015), especially where existing models allocate land among simple crop groups based on assumed average generic classes, such as pasture versus row crops. Monitoring to gather relevant measures of site-specific environmental indicators (e.g., soil and water qualities, productivity) that are associated with long-term management regimes (such as crop rotations) and then potentially incorporating the field data into models (Kröbel et al. 2016) will be important for improved future analysis. Given the history of U.S. agriculture and its shrinking footprint on the overall landscape, as well as the increasing complexity of observed crop rotations, these assumptions merit review and adjustment to align with empirical evidence.

3.7 Future Research

The large variability in results from previous LUC analyses associated with increased U.S. biomass production underscores the need for more consistent and transparent approaches to LUC assessment. One key area of future work could be to integrate the *BTI6* assumptions and outputs from BC1 and HH3 scenarios with global models to estimate potential ILUC effects. The following areas also merit further research—in collaboration with other agencies and stakeholders—because of their implications for the potential land management change and LUC modeling related to biomass production supply chains:

- The implementation of double cropping and the extent to which it is reflected in yield estimates

- The implementation of crop rotations and the extent to which they are reflected or not reflected in land-use and land-cover data
- The characterization of management practices, idle land, pasture, cropland-pasture, and CRP in agriculture models and how the evolving use of these lands can influence measurement of change (i.e., perceived LUC) in land characteristics and environmental indicators over time
- Effects on other markets that could be induced by changes in relative prices of biomass feedstocks
- Historical changes in U.S. land management, primary drivers of change, and the ways that biomass production interacts with those drivers
- The accuracy of assumptions about pasture intensification, based on an analysis of the scientific literature
- Inter-model comparisons for LUC effects of U.S. biomass production scenarios
- Updated empirical studies (such as indexed decomposition analysis) of effects of historical biomass production changes over time and correlation with environmental, social, and economic sustainability indicators
- The role of extreme events, environmental thresholds, and potential buffering effects associated with biomass supply chains
- Definition of a consistent and systematic hierarchy to characterize soil disturbance and management intensities for agriculture and forestry.

To better understand the effects on land cover and land management attributable to particular biomass production or to any specific intervention, monitoring needs to provide data on both the effects over time and the human behaviors that drive those effects. Considering how observed indicators evolve over time (before and after a policy is implemented or before and after management practices are modified, for example), while applying clear and consistent definitions for the effects of concern, can support causal analysis and attribution among multiple drivers of an observed LUC effect (Efroymson et al. 2016).

To understand how *BTI6* compares to other studies requires investigation of the underlying data sets and input parameters (land classification, productivity, elasticity factors, etc.). This research could include the documentation of how different input parameters and specifications influence results. Such inter-model comparison efforts can help to pinpoint the items that require additional research to reduce uncertainty. In the near term, the specifications used for *BTI6* could be compared to another well-documented analysis of LUC associated with a similar level of future U.S. biomass production (e.g., Hudiburg et al. 2016).

3.8 Conclusions

The objective of this chapter was to help readers interpret LUC associated with biomass supply changes from *BTI6* volume 1, with an emphasis on energy and other agricultural crops. As described in this chapter, LUC can refer to land management change or land cover change or both. LUC scenarios are modeled and are therefore uncertain, but they are predictably dependent on model assumptions and input data. The purpose of *BTI6*—to estimate biomass that could potentially be available at particular prices, given a market—necessitated that economic models would be used to estimate changes in land management. Moreover, land management change determines environmental effects that are estimated elsewhere in this report.

The constraints and assumptions applied in models determine the range of results that are possible. *BTI6* simulations are constrained so that no net changes occur in forest and agriculture land areas. Input assumptions regarding land classes and productivity have a major influence on how land is allocated among traditional and energy crops over time within the agricultural sector. The implementation of constraints in *BTI6* effectively reduces potential adverse environmental effects and also reduces the potential biomass supply itself compared to volumes of biomass that could be estimated in the absence of the constraints.

In *BTI6*, the total land area estimated to be managed for energy crops on agricultural land in 2040 is 64 million and 88 million acres under BC1 and HH3 cases, respectively. In both cases, 97% of the total estimated energy crop acreage is managed as perennial crops, such as switchgrass or SRWCs. The remaining 3% of the biomass crop area is composed of biomass sorghum, an annual crop—1.7 million acres in BC1 and 2.3 million acres in HH3. Also, note that the net area in idle land remains constant in all three 2040 scenarios, but amounts and locations of idle cropland vary in each scenario, as idle land rotates with other crops.

The primary type of LUC associated with *BTI6* biomass supply scenarios involves land management practices to transition up to 45 million acres of annual crops to perennial cover by 2040. The environmental effects that are discussed in the following chapters are largely outcomes of this LUC.

The environmental benefits derived from shifting land from annual crops to native perennial cover can be expected to resemble the benefits that have been documented for the CRP program. However, effects associated with monoculture and exotic crops such as miscanthus replacing mixed vegetation on pastureland could be negative.

Under *BTI6* biomass demand scenarios in 2040, 37 million (BC1) or 39 million (HH3) acres of pastureland (approximately 8% of total pasture area in the 2015 agricultural baseline and the BC1 2017 scenario) are managed for the perennial energy crops shown in table 3.4. As described in chapter 2, a proportional share of remaining pasture (56–58 million acres) undergoes improved management (fencing, rotation) to accommodate the biomass crops while meeting other market demands. The assumptions regarding intensification of pasture are required to produce biomass feedstocks within the constraints established that aim to meet other market demands without changing the total area dedicated to agriculture and forestry.

The land management changes described above reflect the purpose of *BTI6*: to identify where and how much biomass is potentially available at particular prices, assuming a growing U.S. bioeconomy. While the scenarios and results can be useful for policy analysis, they are not meant to reflect anticipated policies or predictions. Other LUC studies ask different questions and use different approaches and assumptions. Few LUC models specify all the implications of their assumptions and modeling parameters with respect to land management changes. This is a key component of the *BTI6* analysis. In all LUC studies, the approaches and assumptions should reflect clearly defined research goals.

The ambiguity in overlapping land-use labels leads us to call for science-based indicators and monitoring to test hypotheses related to any environmental effects (e.g., measured changes in soil organic carbon, biodiversity, GHG emissions, etc.) that occur in response to the changes in management required for biomass crops, rather than assuming effects based on perceived "changes" from pasture to cropland. At a minimum, consistent definitions for land cover and land management are required to support a consistent analysis of change over time. This is not easy given that even within the U.S. government, definitions, classifications, and measuring methods vary over time and among agencies. *BTI6* mitigates some of these problems and uncertainties by clearly documenting assumptions and sources and applying a single model to represent sectoral activities (e.g., POLYSYS for agriculture, Forest Sustainable and Economic Analysis for forestry).

The challenges faced when trying to measure LUC associated with biomass production are large. Consistent and transparent use of terms and definitions for land cover classes, crop types and rotations, and characterization of land management are essential elements for improved LUC analysis. The land class definitions and initial acreages applied in *BT16* are based on USDA sources, and the simulation assumptions are consistent with current land uses, laws, and regulations.

Our review of LUC modeling concludes that different approaches attempt to answer different questions, and each approach will generate results that are driven by model specifications, definitions, data sets, and assumptions. Empirical data are not available to support definitive analysis when simulating the future. Therefore, assumed values are applied in models, and the assumptions have a large influence on estimates of LUC and corresponding environmental effects.

Improved monitoring of changes in land cover, crop type, and land management practices (all of which represent different aspects of LUC) is recommended as a basis for reducing uncertainty. Monitoring, including monitoring of changes in clearly defined land attributes, is essential to guide continual improvement in environmental indicators and in the models that simulate them. A U.S. bioeconomy should provide a reliable source of renewable biomass for materials and energy while promoting beneficial LUC, defined as continual improvement in land management practices over the long term, to provide multiple services and benefits to society.

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Appendix 3-A: Terminology, Definitions, and Sources

Science-based sustainability metrics apply methods for consistent measurements. Metrics with relevance to *BT16* and LUC include: crop type (along with the type, carbon stocks [density], evolution, and duration of specific characteristics of vegetative land cover), soil management practices (type, intensity and frequency of tillage, and other activities that disturb or impact soil, water, and vegetation), productivity (above and below ground, both in terms of material harvested and in terms of total NPP [McBride et al. 2011]), disturbance regimes, and environmental indicators analyzed in other chapters of *BT16* volume 2 (e.g., soil carbon, GHG emissions, biodiversity, etc.). Additional metrics are applicable to forest management and LUC (structure, age class, above and below ground carbon, NPP, etc.).

Indirect LUC is not a science-based metric. There is no agreement on clearly defined units, replicable measurement procedures, or published standards for assessing and distinguishing between direct and indirect LUC. As

Table 3A.1 | Published Definitions and Descriptions of ILUC with Respect to Bioenergy Vary Widely and Allow for Subjective Interpretations

Definition	Reference
"When existing cropland is used for biofuel feedstock production, forcing food, feed, and materials to be produced on new cropland elsewhere. This expansion is called indirect land-use change, or ILUC…Because ILUC occurs through global market mechanisms with many direct and indirect effects, it can only be modelled, not measured."	Valin et al. 2015
"Market-mediated or policy-driven shifts in land use that cannot be directly attributed to land-use management decisions of individuals or groups," where land use refers to "the total of arrangements, activities, and inputs undertaken in a certain land cover type."	Verbruggen, Moomaw, and Nyboer 2011
"Whereby mechanized agriculture encroaches on existing pastures, displacing them to the frontier," "takes place when agricultural activities displaced from one region are reconstituted in another one…In such a situation, deforestation at particular locations occurs partly due to events far away," "occurs as loss of land dedicated to a given crop (or production strategy) in one region triggers its expansion in another region."	Arima et al. 2011
"The hypothesis is that the planting of biofuel crops on pastures or croplands in consolidated agricultural regions induces increased expansion of agricultural land in frontier regions to compensate for the lost food production capacity."	Barretto et al. 2013
"Land-use change that occurs outside the system boundary because of the loss of a service that the land provided before the application of the bioenergy activity."	Bird et al. 2010
"If the area (where the cultivation of the biofuel crop is taking place) was previously utilized for other purposes, that activity might be displaced to other areas. This…may occur in the same country where the feedstock is produced, but due to the international trading of crops it is possible that they are displaced to other parts of the world competing with local production of food, feed, and with nature conservation."	Di Lucia, Ahlgren, and Ericsson 2012

Definition	Reference
"Displacing previous production to other land" following "the production of biofuels feedstocks on arable and pasture land."	Fritsche and Wiegmann 2011
"Occurs outside the system boundary because of the displacement of services (usually food production) provided by the land before the change."	Bird et al. 2011
"results in displacement effects, including price-induced changes in global commodity markets, that, in turn, also lead to land being altered from one state to another, with resulting changes in GHG emissions and carbon stocks on that land"	Sanchez et al. 2012
"when pressure on agriculture due to the displacement of previous activity or use of the biomass induces land-use changes on other lands in order to maintain previous level of (e.g., food) production"	Van Stappen, Brose, and Schenkel 2011

illustrated in table 3A.1, LUC and ILUC are ambiguous and subjective terms that have been defined and interpreted inconsistently.

Science-based analysis begins with clear terms and definitions (Dale et al. 2013). The lack of agreement on clear definitions has been noted as an underlying factor confounding analysis of LUC and ILUC (Kline et al. 2011; Warner et al. 2014; ISO 2015). Agreement on definitions, and consistent use aligned with those definitions, are prerequisites for understanding and communicating the effects of bioenergy production on land and for the allocation of causal burden to different factors in the case of a defined land disturbance, such as deforestation (Efroymson et al. 2016).

One common example of LUC cited in the literature is deforestation, a change in land cover typically defined by remote sensing analysis. The change in classification from forest to some other use is easier to observe and measure than most other LUCs, yet presents many challenges. The threshold point at which classification of a land unit changes is independent of actual land use before or after deforestation was identified. Deforestation typically results following decades of changes and incremental degradations prior to the point when a threshold (e.g., 10% canopy cover) is no longer met and land unit classification changes. Another example of LUC found in the literature is when production from cropland (e.g., a field in conventional corn/soy rotation) is used for bioenergy rather than animal feed. In this case, all aspects of land cover and management could remain unchanged while the use of one part of the harvested grain changes. Another example could be when the corn/soy rotation field switches from conventional tillage to reduced-till (a change in management practice). Another LUC could be when the legal status of a parcel changes (even if nothing else changes).

3A.1 Issues of Initial Land Cover Classification are Complex and have Huge Influence on LUC Analysis

For assessing LUC in the United States, USDA (Allison A. Borchers, personal communication) recommends that the National Resources Inventory (NRI) be used. If considering effects on an indicator associated with changes in land cover, please note that the USDA NRI (USDA ERS 2015, USDA ERS 2016) is the government data product designed to provide wall-to-wall consistency in land cover and use. NRI is explicitly designed "to provide legitimate trends and estimates of change across multiple points in time." The NRI classification system uses a different set of definitions than those used by *BT16* and USDA Agricultural Census to distinguish between cropland (363 million acres), pasture (121 million acres), and rangeland (406 million acres) (see table 3A.2). The constraints applied in POLYSYS simulations effectively limit the modeled supply of energy crops to a subset of the cropland and pastureland as defined in the NRI. The 2015 NRI is the only U.S. government source designed to provide nationally consistent data for U.S. land cover and land use over the 30-year period of 1982–2012 (USDA 2015), using the following classes for all non-federal land:

- Cropland including tilled and untilled (cropland pasture) and CRP
- Pasture (seeded and managed for forage crops with periodic inputs, complications can arise as the definition overlaps with some cropland-pasture and some permanent pastures)
- Rangeland (these lands may be managed and seeded but are less intensively managed for grazing than pastureland)
- Forestland (based on USDA Forest Inventory Analysis)
- Water
- Developed, barren and "other rural land" (homesteads, roadways).

USDA explains that there are many different sets of data for land area in a given class, depending on year, data source, and definitions applied. Table 3A.2 illustrates some of the differences. The potential for misinterpretation when doing LUC analysis is high when users re-arrange classes or make assumptions about subcategories such as idle cropland and CRP. For example, by reclassifying those cropland subcategories as grassland, and then declaring a LUC whenever those parcels are put back into production, an analysis can generate large quantities of LUC. And by ignoring the total landscape dynamic of cropland-pasture/grassland rotations, the LUC can be further exaggerated (Kline, Singh, and Dale 2013).

While differences in reported area for a given land cover or use are sometimes purely jurisdictional (e.g., the Bureau of Land Management manages 158 million acres of public pasture/range lands) or depend on whether federal lands are included or excluded (e.g., forest), the choice of data set has huge implications for any LUC analysis. The areas by class cited in the table below vary from 311 million to 408 million acres (over 30%) for cropland; from 409 to 751 million acres (80%) for forest, and 409 to 995 million acres for permanent pasture/range (140%). Even when only private lands are considered, the values vary significantly. For example, Nickerson et al. (2015) show that in 2007, private pasture/rangeland area could range from 409 million acres under NASS surveys to 529 million under NRCS surveys, a 30% difference depending on which source and definitions are used.

When LUC analyses use data from multiple sources and classification schemes, or selectively use data without accounting for "wall-to-wall" land cover in a landscape, it becomes impossible to verify a baseline and undermines credibility of the simulations. These LUC analyses become "shell games" where changes are calculated for selected parts of a landscape without accounting for all the corresponding changes in the remainder of the landscape (Kline, Singh, and Dale 2013). The USDA Economic Research Service provides guidelines for use of data and recommends that the NRI data set be used for LUC analysis involving major land classes.

Table 3A.2 | Land Use and Land Cover Estimates for the United States, by Source (Nickerson et al. 2015)

	Land Use					Hybrid (LU/LC)	Land Cover	
	USFS	BLM	NASS	Census Bureau	ERS	NRCS	USGS	BLM
Scope of Coverage	All forestland	Area managed by BLM	Land in farms	Urban areas	All land uses	All non-federal land	All land and water cover	Area managed by BLM
Category	*Millions of acres*							
Forest/ woodland	751	11	75	-	671	409	600	69
Forest in timber use		11	46	-	544			
Forest in grazed use			29	-	127			
Permanent pasture/range	-	158	409	-	614	529	995	174
Cropland	-	-	406	-	408	390	311	-
Urban areas	-	-	-	68	61	112*	102	-
Rural parks, wilderness areas	-	2	-	-	252	-	-	-
Rural transportation	-	-	-	-	26	*	-	-
Other	-	85	32	-	232	504	373	13
Total area included in estimates	751	256	922	68	2,264	1,944	2,381	256
Total U.S. land area: 2,264 million acres[a]								
Total U.S. land and water area: 2,381 million acres[b]								
Year estimates were derived	2007	2007	2007	2010	2007	2007	2006**	2007

[a] Source: Census Bureau

[b] Source: U.S. Geological Survey

* NRCS combines Urban areas and Rural transportation into a Developed land category. NRCS estimates exclude Alaska.

** USGS data are from 2006, except Alaska and Hawaii estimates are from 2001.

3A.2 Reference Case Considerations for LUC Modeling

Interpretations of outputs from any prospective model should reflect the assumptions and constraints imposed on the model, recognizing that the outputs are not a prediction of the future. The inherent uncertainties of future projections are compounded if results are then used to estimate a “change” compared to some other simulated future or reference system. Effects of LUC are manifested in the differences identified when the biomass scenario is compared to the reference case scenario (Koponen et al. 2016). Projecting management details and effects into the future inevitably involves significant judgment and guesswork for both the biomass and reference scenarios. Independent of the constraints applied in *BT16* and the agricultural reference cases illustrated in this chapter, a range of other plausible reference cases for *BT16* can be considered. Consider the following possibilities for what could occur on the landscape in the absence of bioenergy markets:

- The agricultural land used for energy crops in *BT16* scenarios could return to forest. This possibility is supported by the historical transitions observed in different parts of the United States from the 1800s to the 1980s. However, little evidence supports this hypothesis in more recent decades, given current trends in U.S. land cover (USDA 2015).
- The agricultural land used for energy crops in *BT16* could transition to urban and developed uses, since this has been the predominant type of expanded land use leading to net loss of agriculture land over the past 40 years and continuing to present. However, the rate of loss to developed uses has declined in recent years.
- The agricultural land used for energy crops in *BT16* could transition into cropland pasture and forage crop rotations, as acreages for these land covers tend to expand when row crop prices fall and shrink when row crop prices rise, and because rotations between cropland and pasture represent the largest gross LUC over the past 40 years (Lubowski et al. 2006).
- The agricultural land used for energy crops in *BT16* could simply be left in agriculture and managed for lower yields and/or lower-risk crops. This has been observed in the past, for example, when low corn prices led to fewer acres in high yield (densely seeded) corn, and more acres in lower-yield corn, sorghum, and soy beans. Aspects of this scenario are reflected in the agricultural baseline as total agricultural area remains unchanged but the land in rotation as “idle cropland” increases and other crop and pasture land areas hold mostly constant through 2040.

Historical evidence suggests that at least a bit of all of these reference case alternatives will emerge with or without bioenergy markets. How much transition occurs, where, and which types of transition predominate, will depend on many factors, with bioenergy markets playing a minor role relative to the many more significant policy, environmental, and economic factors that determine crop prices, productivity, access to markets, and sector growth.

The rate of increase in productivity assumed in the agricultural baseline as projected to 2040 is less than the historic average rate of 1.5% per year documented over the prior 3 decades (Wang et al. 2015), a period when total agricultural land area decreased by 82 million acres (USDA 2015) as cropland outputs rose. However, while historic trends on a national basis point to improved productivity and reduced overall cropland area (USDA 2015), studies examining selected areas in the Midwest over short time frames found the opposite trend (e.g., Lark, Salmon, and Gibbs 2015 examined four years [2008–2012]; also see comments on methods and results: Dunn, Mueller, and Eaton 2015; Kline, Singh, and Dale 2013). These contradictions underscore the need for better monitoring and accurate assessment of land management and effects on well-defined, verifiable qualities for soil, water, and vegetation.

3A.3 *BT16* LUC Constraints and Land Allocation Scenarios

BT16 biomass supplies are estimated under assumptions that prohibit net cropland expansion into forestland (or vice versa) and biomass crop harvest on sensitive lands (see chapter 2). One rationale for such constraints is to reduce the number and types of assumptions required for modeling. Another reason is that it avoids many complications involved when intermingling large data sets from different sources, a necessity whenever a model attempts to couple forestry and agricultural models, or attempts to expand beyond the temporal or spatial boundaries of available census and land (remote sensing) data products. Further, in order to model LUC between sectors, value judgments and assumptions are required to define what is expected to cause or deter future exchanges between forestland and agriculture. For example, some studies have attempted to estimate the potential impacts of bioenergy markets on CRP lands (e.g., Walsh et al. 2003; Secchi et al. 2009; Huang, Khanna, and Yang 2011), but the economic model projections for large-scale CRP contract cancellations and non-renewals in response to high corn prices proved to be wrong. Demand for CRP contracts consistently outstripped the funding available for the program and CRP contract area peaked in conjunction with some of the highest corn prices on record.

BT16 scenarios identify sustainable supply potential and therefore prioritize CRP as a land use (27 million acres of CRP were excluded from the scenarios [see table 3.1]). Furthermore, the past four decades of U.S. experience reflect significant swings in commodity prices without notable response in the relative size of the agricultural and forestland areas. This is due in part to a large latent productive potential in U.S. agriculture. U.S. farmers have demonstrated an ability to respond to rising price signals, over-produce and drive prices back down, while consistently using less total agricultural land (USDA 2015; USDA ERS 2015; USDA ERS 2016; Lubowski et al. 2006).

BT16 constrained biomass production to land already in productive agricultural and forestry uses in 2015. The scenarios analyzed in volume 2 also excluded irrigated land. These constraints limit potential impacts in sensitive and special-use lands to previously existing conditions. By definition, no LUC occurs on sensitive lands. The simulations are also designed (see chapter 2) to reduce potential for international indirect effects by prioritizing estimated future demands for food, feed, fiber, and exports through adjustments using price elasticities (see volume 1:360). Additional assumptions and constraints are applied to limit the rate, scale, and types of simulated transitions from conventional crop management and pasture to management for energy crops.

If *BT16* had not incorporated assumptions that limit biomass potential from less sustainable sources, the projected biomass supply at any given price point would be larger. There are several reasons to support the assumed LUC constraints. First, changes in agriculture and forestry production systems take time and the incremental nature of change is reflected by the constraints applied. Second, current U.S. energy and land policies protect water, soils, and other ecologically sensitive lands (e.g., see EPA 2016; NRC 1993) and explicitly exclude biomass from federal forests and from land that was not already in agricultural production in 2007 (EPA 2010). Third, the constraints are consistent with historic land-use trends as discussed below (USDA 2015). Fourth, such constraints are consistent with the U.S. strategic plan for decarbonizing the economy (White House 2016) and nationally determined contributions to the Paris Climate Accords, and the U.S. Bioeconomy Vision (BRDI 2016). Finally, eliminating these constraints would be inconsistent with the *BT16* aim to estimate sustainable biomass supply.

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