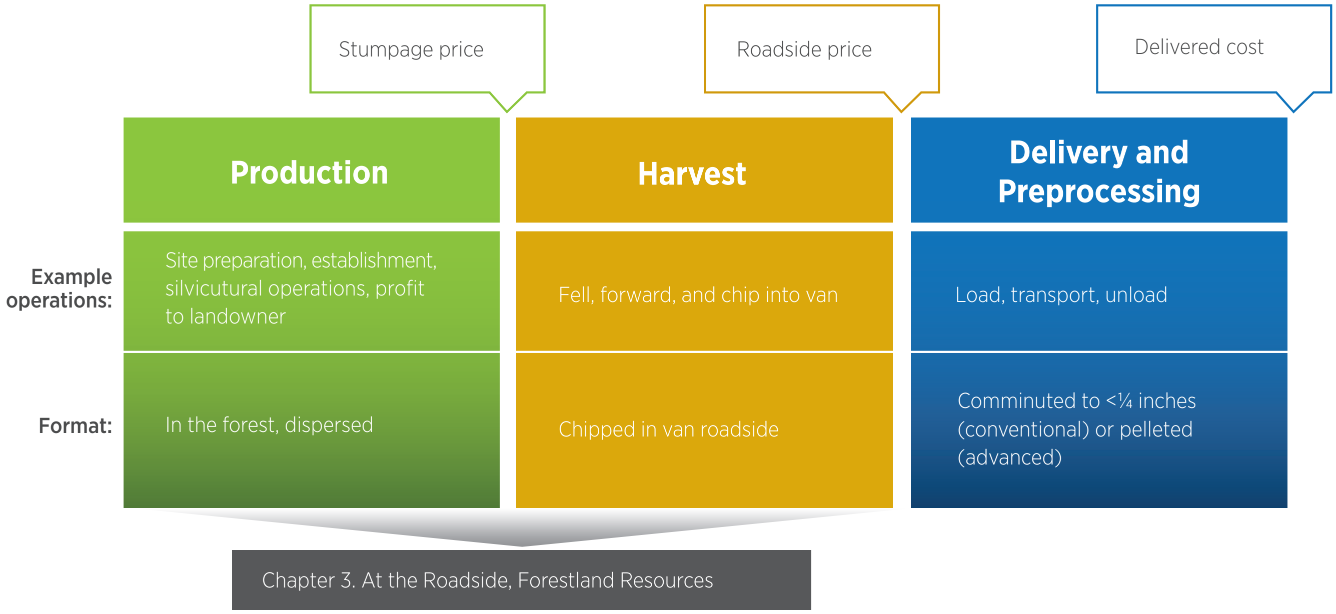
03 | At the Roadside: Forest Resources



3.1 Background and Introduction to the Forest Resources Analyses

3.1.1 Chapter Structure

Chapter 3 assesses the availability of forest resources to the roadside. Not all woody feedstocks are discussed in this chapter. Logging residues and whole-tree biomass are included. Other feedstock categories have been moved to chapter 5 or are redefined to be included in the whole-tree biomass category. New methodologies and data are used in the assessment to estimate woody biomass as a function of price, year, and scenarios based on national wood demand.

This chapter has six major parts. Section 3.1 provides background and information useful to understanding the context for analyzing forestry resources. This section presents useful definitions as well as feedstock labels and types that have changed since the 2011 *BT2*. It also describes the underlying sustainability assumptions used in the model, and issues in federal land management. Although the model is only for the conterminous United States, the biomass potential in Hawaii and Alaska is also introduced.

Section 3.2 explains an important part of the model inputs. Descriptions of the underlying harvest systems, operational attributes, and costs are presented in this section. New costs were developed for this section, using a different method than in the 2011 *BT2*.

Section 3.3 explains conventional wood and biomass demand scenarios—another important aspect of the analysis. These scenarios are used from the U.S. Forest Products Module/Global Forest Products Model (USFPM/GFPM). The projected conventional products demands are used to estimate logging residue supply, and the biomass demands are used to develop supply curves.

Section 3.4 is the primary section that describes the new Forest Sustainable and Economic Analysis Model (ForSEAM) forestry model and its outputs. A very important aspect of the model is that it first solves for conventional timber demands (i.e., sawtimber and pulpwood). Logging residues are estimated as a function of the conventional timber production. Then the model solves for additional biomass from tree stands of designated sizes to meet the biomass demands in the selected scenarios. Shadow prices are used to determine the cost at which the demands will be met. These shadow prices and biomass demands are then used to develop cost curves that provide levels of biomass at selected costs. The outputs are shown for $40, $60, and $80 per ton but were also run at higher cost levels. The amounts of biomass estimated to be available by cost and year are reported as the forest resources to roadside in this report.

Section 3.5 is a unique addition to this report because it is a comprehensive market analysis. The Subregional Timber Supply (SRTS) inventory and harvest model for the U.S. South is used. This is added for several reasons:

- The newly developed ForSEAM had to be verified. A published model in use, SRTS, was adopted for that purpose.
- *BT16*, like the earlier reports, is a supply analysis; the forestry supply is now being modeled as a function of demand. Thus, a market assessment of the South was completed to demonstrate the interactions between market demands and supply.
- It is important to understand the impact of increased pellet production, especially in the southern United States, on both demand and future supply.

This section assesses the factors that influence the demand for and supply of wood for both energy and conventional products in the South. A partial equilibrium timber market model was used to evaluate a set of combinations of these factors to illustrate the impacts of the supply and demand factors on market outcomes. Using subregions of the U.S. Coastal South, evaluations were completed on (1) competing pulpwood demands, (2) declines in sawtimber harvest, (3) substitution of mill residues for small roundwood, and (4) changes in timberland area. The section discusses the simulations of market impacts on the prices, inventory, and removals of timber, as well as timberland area by management type.

Section 3.6 summarizes the available biomass from forest resources at roadside. Discussions of the results and their implications are included in this section. Finally, section 3.7 discusses additional research that would be useful in extending and improving the analysis of available biomass potential from U.S. forestland.

3.1.2 Chapter Summary

Chapter 3 provides estimates of primary biomass (removed from the land) from timberland-only forest resources at selected costs to roadside. Total costs to the conversion throat that include transportation and preprocessing are described in chapter 6. It is important for the reader to understand that roadside costs are not the total cost of a feedstock at a conversion facility. Also when biomass availability is reported by roadside cost, the actual amount of biomass transported to and useable at the biorefinery may be less because of losses, screening and separation, and spoilage. In this chapter, the availability of logging residues from conventional harvest and from whole trees harvested explicitly for biomass are modeled. Two other primary forest biomass feedstocks, “other removal residues” and “thinnings on other forestland” are discussed in chapter 5 and are counted as wastes in *BT16*, unlike in the 2011 *BT2*. The estimates are developed for private (industrial, nonindustrial, and tribal) timberland and federal timberland. They are based on significant underlying assumptions regarding the available land base, ratios of types of harvest, residue retention rates, growth rates, land cover and use management, growth/harvest limits, and other implications that need to be understood. These estimates are conservative but provide a good basis for understanding forest biomass inventory and analyses. Hopefully, this assessment will be of value to others to further the work begun in this chapter.

In the newly developed forestry model, ForSEAM, the current Forestry Inventory and Analysis (FIA) database provides the basis for determining how demands for conventional products such as sawtimber and pulpwood will be met up to 2040. The demands are based on a set of projections for U.S. forests and forest products markets under varying market conditions. The USFPM/GFPM forest products market model—linked with the SRTS inventory and harvest model for the South—was used to project the harvest removals, inventory, price, and timberland area that result from three levels of wood biomass feedstock demands. The baseline scenario (Baseline_ML) represents the lowest level of wood energy demands. In the moderate and high wood energy demand scenarios, feedstock prices rise sufficiently to reduce paper and paperboard production levels by 1% and 3%, respectively, below baseline in 2040. In the high-demand scenario, impacts on prices are ameliorated somewhat by an assumed increase in investment in southern pine plantation management that would be expected as prices for softwood small roundwood increase. In addition, increases in timberland area (in USFPM/GFPM) are projected based on the assumption that increasing prices lead to increased land rents, and increasing land rents lead to increased conversion of marginal agricultural land to timberland.

The linear programming model ForSEAM was constructed to estimate forestland production for traditional forest products and to meet biomass feedstock demands. The supply component includes general forest production activities for 305 production regions or agricultural statistic districts and is placed in a national linear programming model. Each region has a set of production activities defined by the scenario demands. These production activities include sawtimber, pulpwood, and biomass (fuelwood is defined as biomass for this report). Sawtimber and pulpwood harvest activities generate forest residues that can be harvested for energy and bioproducts, and whole trees can be removed for biomass under some specific assumptions of size. High-value sawtimber is never harvested for biomass.

The model estimates biomass potential from timber stand information across the conterminous United States. An important variable is tree diameters that are classed as average stand diameter. Class 1 has a diameter of >11 inches, class 2 has a diameter of 5–11 inches, and class 3 has a diameter of <5 inches. The model estimates the costs, the locations, and the kinds of biomass available to meet a prescribed demand. The demands are derived from the Forest Product Demand Component. This component is based on six USDA Forest Service scenarios with estimates developed by USFPM.

Not all forestland in the United States is considered in the analysis; only the conterminous United States is included. All protected, reserved, and non-roaded forestland is excluded. The analysis is restricted to only timberland instead of all forestlands. Although conventional products are removed from slopes greater than 40% using cable systems, no logging residues are recovered, leaving 100% on the site. A major criterion is that the harvest in each state does not exceed annual growth. There is no road construction, as only forest tracts located within a half mile of the roads are harvested. The current-year forest attributes reflect previous years' harvests and biomass removals, which means that dynamic stand tracking of forest growth is incorporated into the model and the analysis. Another underlying assumption is the retention of biomass to protect the site and maintain soil carbon. Also, there was no conversion of natural stands to plantations.

A final major assumption is that there are no forestland losses over the modeling time period and no land cover changes in the model. This means that fast-growing plantations specifically for biomass are not established after the harvest of a natural stand. All harvested stands are assumed to regenerate back to, and according to, the original cover. Natural stands regenerate to hardwood, softwoods, or mixed, as they were previously. Plantations are regenerated as plantations. An unfortunate downside to this approach is that insufficient amounts of biomass are generated in the out years of the modeling period to meet the high-demand scenarios. These scenarios were developed based on the establishment of millions of acres of plantations to be grown for biomass. As will be discussed in more detail, there are several changes involved with using the model that are more restrictive in biomass availability than in the 2011 *BT2*.

Shadow prices[1] are developed for the demand scenario biomass amounts. The shadow prices and the associated acres for the scenario demands (dry tons of biomass) are reported by product type (logging residues or whole-tree biomass), as well as other parameters of the study, across selected years. Conventional timber products are not reported in this chapter but will be made available on the Bioenergy KDF. All the outputs will be made available in various forms and formats.

These shadow prices for the scenario demands are used to develop conventional supply curves to estimate biomass availability at roadside for a given cost. A summary of available biomass in the baseline scenario using an example cost of $60 per dry ton to roadside is shown in table 3.1. The out-year biomass availabilities are slightly reduced with the underlying assumption that no biomass plantations were established on forestland for the baseline example. In other scenarios, such as the supposedly highest biomass demand, there were even more significant reductions in out years, especially 2040, because biomass plantations were not established.

Table 3.1 | Summary of Forest Biomass of the Baseline Scenario by Ownership and Year at a Cost of $60 per Dry Ton to Roadside

Ownership	2015	2017	2020	2025	2030	2035	2040
	Million dry tons						
Private	66.5	68.1	73.6	64.9	61.6	66.4	64.5
Federal	15.8	19.8	20.5	20.4	19.6	19.5	17.0
Total	**82.3**	**87.9**	**94.1**	**85.3**	**81.2**	**85.9**	**81.5**

The market analyses show that the timber markets in the South are affected by the age class distribution and broad management types in the current forest, and these markets in turn affect future age class distributions and management types. The product markets for large- and small-diameter timber are linked, as they both are produced at each point in time on a single acre of timberland, especially in natural stands; trees on plantations are more uniform in size. The only way to get large-diameter trees for sawtimber is to allow small-diameter stands to age. Markets are linked to these changing diameters across the South.

Competition for pine small roundwood in some regions will likely intensify with increased demands for wood biomass feedstocks, leading to higher prices and some potential reductions in other uses, as shown in the Mid-Atlantic subregion. Past reductions in conventional demand for hardwood small roundwood imply that prices for this feedstock will likely not increase as rapidly as prices for pine small roundwood.

[1] In the strictest sense, a shadow price is any price that is not a market price, but the term usually also carries the connotation that it is an estimate of the economic value of the good or service in question. See http://web.stanford.edu/group/FRI/indonesia/documents/gittinger/Output/chap7.html.

An increase in demand for small-diameter roundwood alone, however, is not likely to affect the demand for sawtimber. The prices for sawtimber will likely continue to stay low in such areas as the Gulf Coast, reducing landowner incentives to replant, as well as reducing the availability of land for replanting. The harvest of mature trees provides stand regeneration opportunities. The amount of sawtimber harvest and the subsequent regeneration opportunities affect the availability of "thinnable" acres in the 10–15 years following the final harvest and thus affect the availability of the next generation of small-diameter softwood removals that can be used for biomass.

A potential recovery in the housing and lumber markets leading to renewed sawmilling has the potential to increase the availability of sawmill residues, which may ease the pressure on the small roundwood resources and thus ameliorate price increases. The impact is greatest in areas that have active sawmilling industries and smaller average-diameter sawmill inputs, such as the Southeast Coast region.

Finally, timberland has been shown to respond to land rents, and increased demand with a quasi-fixed inventory will lead to higher prices and thus higher land rents. In this way, increased demand for feedstock for wood energy can contribute to increased timberland area (or at least to smaller decreases in timberland area).

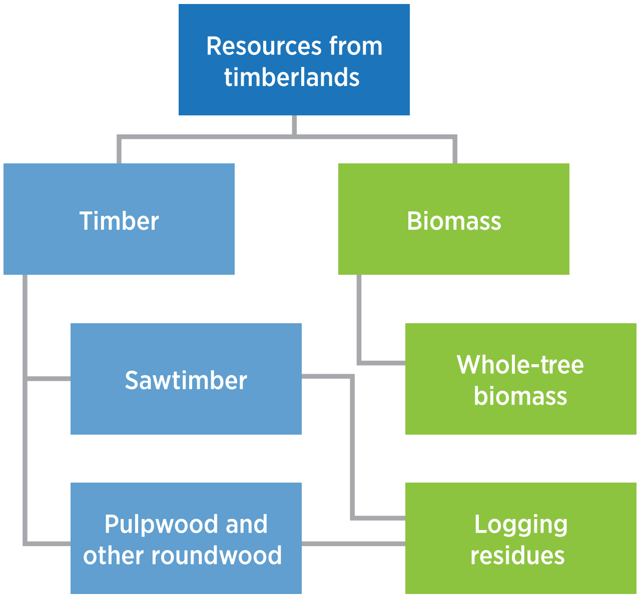
3.1.3 Introduction

This chapter provides forest biomass supply curves to estimate the available tonnages of forest biomass at given roadside costs, by county, by year, and by scenario. The content is similar to that in the 2011 *BT2*, but it differs in some major ways. Some of these changes are identified and discussed in previous chapters, and all are discussed as appropriate in this chapter. Generally, the changes are the following:

- Feedstock types are slightly modified.
- An economic model is used to develop supply curves for biomass for various timber and biomass demand scenarios.
- Some underlying assumptions and coefficients are modified.
- Wood waste resource analyses are now separate and discussed in chapter 5.
- Federal lands are included in the forest resource analysis.

Forest biomass as feedstocks includes (1) wood wastes in forests, at mills, and from landfills; (2) harvests from silvicultural treatments such as thinning, fuel reduction, and regeneration cuts; and (3) purpose-grown trees on plantations. Trees and tree components from land conversion practices such as urban expansion into woodlands or right-of-way clearing are also a source of wood waste. A more formal breakdown of forest wastes categories is shown in the feedstocks taxonomy of chapter 1.

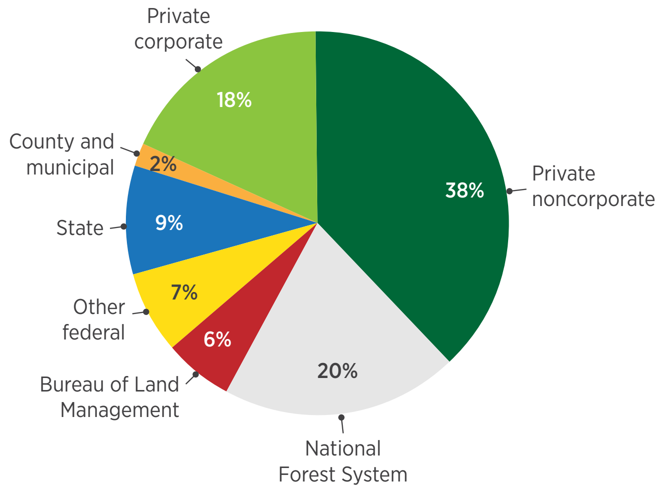
Figure 3.1 | Biomass resources from timberland



This chapter discusses only primary (direct from the land) biomass resources from timberland (fig. 3.1). Land type definitions are shown in text box 3.1 (Smith et al. 2009). The feedstocks included in this chapter are forest residues (i.e., logging residues) and whole trees cut explicitly for biomass uses (i.e., whole-tree biomass). Only biomass on timberland in the conterminous United States is used in this analysis. Table 3.2 shows the amount of land, forestlands, and timberlands in the United States and in the conterminous United States. Figure 3.2 details the ownership of forestlands. Section 3.4 reports the available acres in the model and then the number of acres treated each year. Some restrictions and underlying assumptions reduced the amount of available timberland in the model.

Two classes of forest feedstocks—“other removal residues” and “thinnings on other forestland”—have been moved to chapter 5 and are being considered as secondary resources. A new model used to estimate primary feedstocks was not capable of handling these two feedstock types, so the methodology used in previous versions of this report was applied to estimate the biomass availability for these feedstock types.

Figure 3.2 | Forestland ownership in the United States



Source: Data from USDA Forest Service (2012).

Text Box 3.1 | Definitions

- **Forestland**—Land at least 120 ft wide and 1 acre in size with at least 10% cover (or equivalent stocking) by live trees of any size, including land that formerly had such tree cover and that will be naturally or artificially regenerated.
- **Timberland**—Forestland that is producing, or is capable of producing, in excess of 20 ft^3 per acre per year of industrial wood and not withdrawn from timber utilization by statute or administrative regulation.
- **Other forestland**—Forestland other than timberland and productive reserved forestland.
- **Reserved forestland**—Forestland administratively removed from production.

Primary forest biomass resource categories have changed over time in the series of Billion-Ton reports, mostly because of the changing analytical methodologies. In the original 2005 *BTS*, the primary forest resources were (1) logging residues, (2) fuel treatments from timberland and other forestlands, and (3) fuelwood. In the 2011 *BT2*, primary forest biomass types were (1) fuelwood for current use only,

(2) composite operations—half logging residues and half thinnings from timberlands, (3) other removal residues, (4) thinnings from other forestlands, and (5) conventionally sourced wood (pulpwood).

The composite operations category was added in the 2011 *BT2* to handle the conceptual transition from a two-pass operation to an integrated operation. In a two-pass approach, logging residues are left at the stump during the stand harvest for later removal. In an integrated system, timber and biomass are harvested together. As it was difficult in *BT2* to model the transition from non-integrated to integrated systems, *BT2* makes an assumption to avoid counting the biomass as both logging residues and integrated thinning biomass. A conservative estimate was 50% of the logging residue supply estimates and 50% of the thinning supply estimates, which means that over the time of the projection, about half will come from the recovery of logging residues and half from thinnings.

Table 3.2 | Forestland and Timberland in the United States

Type of land	United States	Conterminous United States
Total land	2.3 billion acres	1.9 billion acres
Forestland	751 million acres	623 million acres
Timberland	514 million acres	475 million acres

Source: Data from USDA Forest Service (2012).

In *BT16*, the primary feedstocks from timberlands were again changed, as the new model can differentiate spatially and temporally between logging residues and the cutting of whole trees (table 3.3). The underlying assumption is that all harvesting of residues is integrated—the biomass portion (logging residues) is harvested at the same time as the conventional timber.

“Conventionally sourced wood” in the 2011 *BT2* is categorized as “whole-tree biomass” in *BT16*. The new whole-tree biomass category is commercial and noncommercial trees harvested for biomass from a stand in which no commercial trees are harvested for conventional products—all trees harvested go to

Table 3.3 | Forest Resources Feedstock Type Changes

Feedstock	2005 *BTS*	2011 *BT2*	*BT16*
Logging residues	•	•	•
Composite		•	
Thinnings (timberland)		•	
Thinnings (other forestland)		•	•
Other removals		•	•
Conventionally sourced wood		•	
Whole trees			•

Note: Thinnings (other forestland) and other removals are covered in chapter 5. Thinnings (timberland) are included as logging residues or whole-tree biomass.

biomass uses. The stand can be clear cut (all trees removed) or thinned (partial cut of trees in the stand). In the model, this biomass type was harvested only when there was not a sufficient amount of logging residues to meet the biomass demand in a scenario. (The process is explained in detail in subsequent sections of this chapter).

As trees grow and mature, their value usually increases greatly along with their size and form. The use of wood for energy purposes is not competitive in the market compared with the use of wood for paper, board, and lumber products. As a result, only younger stands and smaller-diameter stands are harvested as whole-tree biomass.

Logging residues are available only when trees are harvested for conventional timber markets; when those markets are saturated, logging residues are no longer available as a source of biomass. In this analysis, logging residues are assumed to be harvested as an integrated product, along with the conventional sawlogs and pulpwood, at a relatively low extra cost compared with whole-tree biomass. Therefore, all available logging residues are harvested first in the model to meet the biomass demands in the scenarios. When the demand is greater, then the model solves for the lowest-cost whole-tree biomass to supplement the demand.

Forest biomass (e.g., loblolly pine) is a unique resource as a biomass feedstock and an economically feasible alternative or complement to conventional forest product systems. The current resource, grown primarily for pulpwood and other traditional forest products, is the result of decades of research in plantation management. Because of its cultural acceptance, extensive management knowledge, established genetic improvements, and high yields, pine is a key candidate feedstock to support the emerging biomass industry at a feasible scale in the southern region. Kantavichai, Gallagher, and Teeter (2014) assessed the feasibility of loblolly biomass plantations and compared breakeven prices for a short-rotation biomass plantation with those for a traditional timber management plantation. For landowners, if biomass stumpage prices reached $10.50 per green ton (or higher), biomass plantations would be feasible; furthermore, biomass plantations can benefit landowners interested in diversifying their management portfolios. Munsell and Fox (2010) also examined the feasibility of increasing biomass production from harvested pine sites and idle farmland by looking at yield simulation models and financial analyses. Results suggest that with intensive management, a mixture of conventional and biomass pine (on harvested sites) could be profitable for landowners.

Land use change in forestry has consisted primarily of the conversion of forestlands to other uses such as residential and commercial infrastructure (Bentley and Steppleton 2012). In this report, there is no land use change from/to forestry and non-forestry use. Neither are there any exchanges between agriculture and forestry, as the ForSEAM and the POLYSYS models are not linked.

Another significant underlying assumption is that there are no changes in land cover (i.e., harvest was followed by reestablishment/continuation of the same cover type). There are no additional plantations established on natural stand sites for biomass. Current plantations are regenerated as plantations but are not necessarily harvested for biomass, as is explained in section 3.4. The assumption makes it difficult to meet future demands in this report.

As reported in the 2011 *BT2*, the component ratio method (CRM) was used for calculating the non-merchantable volumes of the merchantable trees (Heath et al. 2008). The method was again used in *BT16*. The FIA program of the USDA Forest Service adopted the CRM in 2009 for estimation of the above-ground live tree component biomass. The approach is based on (1) converting the sound volume of wood in the bole to biomass using a compiled set of wood specific gravities, (2) calculating the biomass of bark on the bole using a compiled set of percent bark and bark specific gravities, (3) calculating the biomass of tops and limbs as a proportion of the bole biomass based on component proportions, (4) calculating the biomass of the stump using equations, and (5) summing the parts to obtain a total aboveground live biomass. The CRM incorporates regionally specific volume models by species and species group (Domke et al. 2013).

The methodology has had some scrutiny. Domke et al. (2013) report that biomass and carbon stock estimates decreased, on average, by 16% for the 20 most common species across the 48 conterminous states. A similar volume-to-biomass conversion method significantly underestimates biomass from 6.3% to 16.6% for selected species (Zhou et al. 2011). Heath et al. (2008) report lower biomass estimates with the CRM. Mater (2015) reports that CRM underestimates for species outside the west range from 5% to 36%, with 15% a mid-range value for northern and southern species.

The CRM was used in *BT16* primarily for consistency with the 2011 *BT2* and compatibility with the FIA database. The CRM is consistently applied across the United States in the FIA (Woodall et al. 2011). As improvements are made in the CRM, such as developing a method of estimating merchantable bole biomass for the sawlog component and the component above the minimum sawlog top diameter for timber species in the FIA program, more accurate and better biomass estimates will be available in the database. Additional efforts are ongoing in the continued refinement of FIA's modeling/estimation procedures to estimate biomass in the future (Woodall et al. 2011).

Woody crops for energy are considered in chapter 4, as they were in the 2011 *BT2*. That is because the agricultural model uses agricultural land for energy crops. The forestry analysis used a new model (described in detail later in this chapter) that can look at land change; however, it is not yet capable of linking agricultural and forestry lands together to analyze land use change between the two sectors. Since there are no definitive data, and there are many uncertainties surrounding both technical and social aspects of land use decisions in forestry, a simplifying assumption used in this analysis was that land use in forestry did not change. All timberlands are assumed to remain in forestry over the analysis period. Furthermore, no intensification changes are made in the stand types. All stands regenerate back to the previous stand type. For example, natural pine or mixed stands are not put back into fast-growing plantations. Harvested plantations are assumed to be regenerated artificially as intensively managed plantations.

3.1.4 Federal Lands and Fire

In the 2011 *BT2*, biomass from federal lands was estimated separately from biomass from private lands for most feedstock types. Again, in this analysis, federal lands are estimated separately, but they are included in the model. The primary reason for separating them is that biomass from federal forestlands—the largest component of public lands—is excluded from being a qualifying renewable biomass under EISA.[2] Biomass is estimated for all private and federal ownership categories, even though federal lands do not currently qualify under the RFS. Federal lands are included because they are a valuable source of biomass, and because reducing and removing biomass is one way of improving the resiliency of federal lands under stress from droughts, pests, and fire.

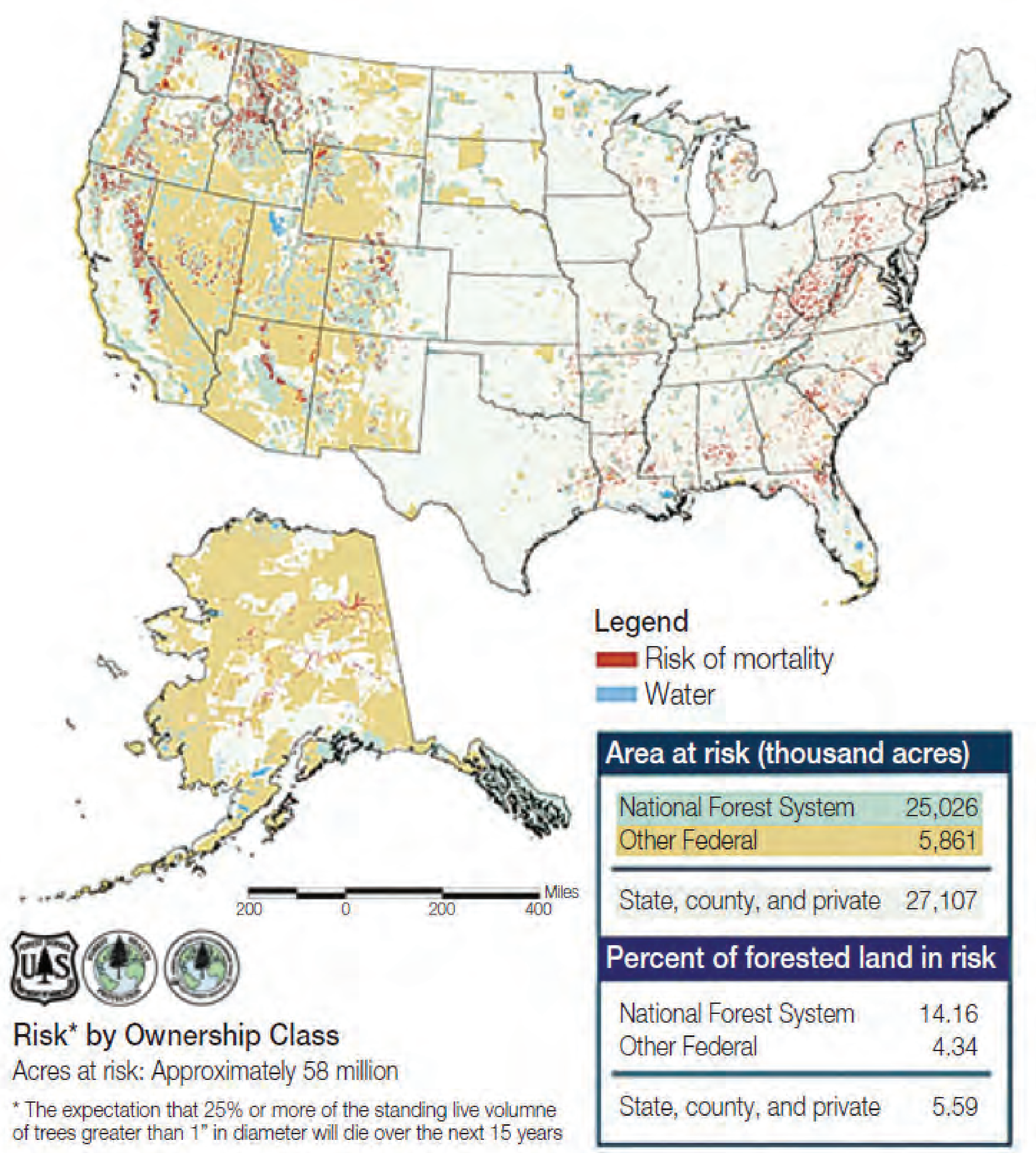
From 2005 to 2014, almost 628,000 wildfires consumed nearly 65 million acres in the United States, representing a serious environmental and economic threat that is extremely costly to battle (NIFC 2016). Although much of the annual variation in the number and size of wildfires (fig. 3.3) reflects climate variation, it is more generally an indication of poor forest health. Much of the fuel for wildfires results from overstocked forestland with small-diameter trees. Those conditions make trees generally more susceptible to attacks from insects and disease, which lead to

[2] Energy Independence and Security Act of 2007, Pub. L. 110–140, 121 Stat. 1492, http://www.gpo.gov/fdsys/pkg/BILLS-110hr6enr.

early mortality and create an ideal source of fuel. The problem is expected to intensify as weather patterns continue to change, with more severe droughts and precipitation shifts in the future (Bentley and Stepleton 2012). Figure 3.4 illustrates the vast land area where high tree mortality (>25%) from insects and diseases is expected. Note that the issue is not limited to the West but impacts forestland across the nation.

Figure 3.3 | Land area impacted by wildfires annually (2005–2014) in the United States

Figure 3.4 | Areas with potential risk of tree mortality greater than 25%



Source: USDA Forest Service, Forest Health Monitoring Program

Wildfire suppression costs routinely run in the billions of dollars every year, leading to intense interest in developing effective remediation approaches. Remediation would involve reducing stocking through various types of harvest operations. There are clear access challenges; however, a major issue is the absence of attractive markets for what ultimately is small-diameter, low-value trees. Although the Forest Service has sold a not insignificant tonnage of woody biomass over the last 5 years to address forest health concerns, the total amount has declined from 2.3 to 1.6 million dry tons (table 3.4). The decline can be attributed, in part, to the limited value of the raw material. The availability of new technology to effectively utilize this woody residue for the production of fuels and industrial chemicals would ultimately increase the value of the resource and expand the volume of the feedstock for the biomass industry. This outcome would have important ramifications for forest health across the country, as well.

Table 3.4 | Amount of Biomass Sold for Energy and Wood Products from National Forestlands, 2010–2014

Year	Biomass sold (dry tons)		
	Bioenergy	Bioproducts	Total
2014	1,099,527	500,126	1,599,653
2013	1,429,677	298,848	1,728,525
2012	1,398,284	535,500	1,933,784
2011	1,473,071	510,426	1,983,497
2010	1,651,419	643,635	2,295,054

Source: Data from NIFC (2016).

The Bureau of Land Management (BLM) manages 58 million acres of forest and woodlands. They include pinyon-juniper and western juniper woodlands, Alaska boreal forest, and 2.2 million acres of the Oregon and California Railroad Revested Lands in western Oregon, as well as forests in the Rocky, Sierra Nevada, and Cascade mountains (BLM 2014). In 2014, BLM sold about 116,559 green tons of biomass (including firewood permits and biomass chips from Stewardship contracts). In 2014, BLM completed 28,875 acres of thinnings. These acres contribute to the nearly 117,000 green tons sold, but not all thinnings result in a permit or contract to convey material.

3.1.5 Sustainability

In the 2005 *BTS*, an underlying principle was the sustainability of the selected feedstocks, which are known to be sustainable under proper production, harvest, and use regimes. The 2011 *BT2* took such assumptions further with supporting analyses and the incorporation of delimiters in land use, location, inputs, removal levels, systems, and operations with the goal of maintaining environmental quality. *BT16* volume 1 uses similar constraints and is followed by more in-depth environmental sustainability analyses in volume 2.

For forestry resources to roadside, assumptions used in the availability analysis of volume 1 are to

- Remove fragile, reserved, protected, and environmentally sensitive forestland
- Access stands without road building
- Use production and harvest systems specified for particular species, timber size, and land condition to minimize impacts
- Manage residue removal levels to protect the soil and water and to ensure long-term productivity
- Assume the use of best management practices (BMPs) and include in cost estimates
- Restrict harvest levels to ensure that timber growth always exceeds harvest at the state level
- Leave at least 30% of logging residues on-site to protection soil, provide habitat, and maintain soil carbon.

Compliance with BMPs is very important to forestry sustainability. BMPs are usually voluntary, but they can have some compliance enforcement or regulatory oversight. Many of the eastern states have compliance monitoring programs to assess the application of these BMPs or guidelines on public and private forestland (Phillips and Blinn 2004). The approaches among these states to collecting on-site monitoring data (measuring compliance) and evaluating sites are variable. A survey of eastern states found that almost all the southern states monitor the application of BMPs, but proportionally fewer of the northern states have established compliance monitoring programs. The state forestry agencies provide the leadership for these programs in most of the eastern states. States that monitor tend to evaluate all public and private forestland owner categories located within their states. In general, northern states monitor a broader array of site resources (e.g., cultural resources, visual quality) compared with southern states, which focus on water quality and wetlands protection. However, northern states focus their monitoring on timber harvesting, forest road construction, and maintenance.

Forestry BMPs usually focus primarily on forest water quality from timber harvesting, site preparation, forest road construction and maintenance, stream crossings, and other categories of forest operations. Cristan et al. (2016) reviewed the literature on BMP effectiveness and concluded the literature indicates that forestry BMPs protect water quality when measures are constructed correctly and in adequate numbers. Another literature review by Anderson and Lockaby (2011) concluded that a limited number of studies have quantified BMP effectiveness in reducing sediment runoff. Three paired studies of forested watersheds in the eastern United States found that BMP efficiencies ranged from 53% to 94% in sediment and nutrient loading reductions (Edwards and Willard 2010).

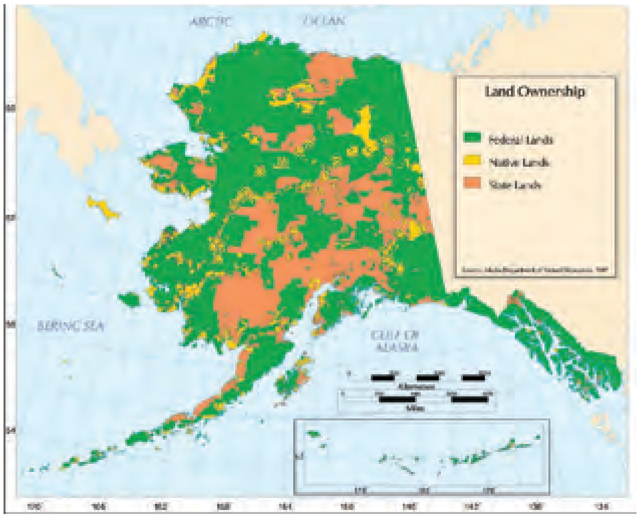
3.1.6 Alaska and Hawaii

Neither Alaska nor Hawaii is analyzed using the model because of the lack of data. Alaska has forest inventory data for portions of the state; Hawaii is now starting to conduct forest inventories.

The approximate forestland area of Alaska is 127 million acres. Alaska is the only state that has never had a complete forest inventory (PNW 2011). The southeast and south-central regions of Alaska are regularly inventoried. This area contains about half of the state's timberland. Public agencies manage 88% of the 15.3 million acres of forestland in the coastal region of Alaska (PNW 2011). Private owners hold about 12% of the forested area in the region but about 24% of timberland. The same assessment of nearly 12 million acres of available forested land estimated only 3.7 million green tons of annual growth—a limiting factor for accessing biomass.

There is increasing interest in the use of biomass in southern Alaska, but use is constrained by high transportation costs, currently inadequate harvesting systems, and limited information on available biomass

Figure 3.5 | Lands in Alaska by ownership



supply. There are more than 1.3 billion tons of biomass stored within the live trees of coastal Alaska. Nearly 83% of the live forest biomass in coastal Alaska is on national forestland managed by the USDA Forest Service. How much of this standing biomass can be harvested is difficult to determine primarily because of lack of accessibility and the drop in timber sales. The harvest in southeast Alaska has dropped substantially in recent years because of lawsuits over sales of timber from the Tongass National Forest, lower timber inventories on some native corporation lands, high operating costs throughout the region, and shifting global markets and competition (Barrett and Christensen 2011). Assessment of the biomass potential in Alaska continues to be developed.

Hawaii has almost 2,000 acres of forest area that have about 48% forest cover (FIA 2012). However, the islands are just now being measured for the Forest Service FIA. Some old assessments have been completed for merchantable wood estimates that provide some level of biomass potential analysis (see Turn, Keffer, and Staackmann 2002). The Hu Honua bioenergy facility is developing a 30 MW power station that uses eucalyptus plantation and wood residues.

3.2 Timber and Biomass Harvest Costs

3.2.1 Methodology

For the 2011 *BT2*, harvest costs for simulated thinnings and conventionally sourced wood were calculated using an adapted Fuel Reduction Cost Simulator (FRCS) (Dykstra, Hartsough, and Stokes 2009; Fight, Hartsough, and Noordijk 2006). The FRCS estimates the biomass-to-roadside cost by three system types: (1) whole-tree harvesting with mechanical felling and ground-based extraction, (2) whole-tree harvesting with manual felling and ground-based extraction, and (3) whole-tree harvesting with manual felling and cable-yarding (DOE 2011). The cable-yarding system is used when the slope of the harvested land exceeds 40%. All biomass is chipped, and the chipping cost is added to the harvest cost for the thinnings. For logging residues, FRCS is used to calculate chipping costs only, as the underlying assumption is that logging residues are felled and extracted along with the merchantable trees; thus there is no harvest cost for biomass as a by-product. Fuel costs and labor rates are adjusted according to the region of the United States modeled. Stands over 0.25 mile from an established road for cable-yarding systems, and between 0.5 and 1.0 mile for ground-based systems, are too expensive to be considered, although they are not excluded.

A different approach is used to estimate harvest costs in this study. The harvest costs and chipping costs are estimated as input to ForSEAM (see section 3.4.). Specifically, input costs are derived for each of the following parameters:

- **U.S. region:** Northeast, North Central, South, Inland West, and Pacific Northwest
- **Stand type:** Upland hardwood, lowland hardwood, natural softwood, planted softwood, or mixed softwood/hardwood

- Stand diameter class: Class 1, diameter >11 inches; class 2, diameter 5–11 inches; and class 3, diameter <5 inches
- Cut (type of harvest): Clear cut or thinning (partial cut)
- Products: Timber (merchantable products of sawlogs and pulpwood), logging residues (forest residues), and whole-tree biomass
- Harvest method: Full tree or cut-to-length
- Ground slope condition: ≤40% or >40%.

A deterministic spreadsheet model developed by the Consortium for Research on Renewable Industrial Materials (CORRIM) was used to estimate the input harvest costs to ForSEAM. The CORRIM model calculates cost, fuel, and chemical outputs (Oneil et al. 2010; Johnson et al. 2004) and had been modified previously to estimate the costs of harvesting forest residues (Johnson, Lippke, and Oneil 2012). In this particular version, the spreadsheet model was used to calculate machine and labor costs, with fuel costs as a part of the machine rate.

3.2.2 Harvest Systems

The CORRIM spreadsheet provides individual machine costs by region and by equipment attributes such as engine horsepower, undercarriage (tracks or tires), capacity, and use (clear cut or thinning). These machines must be assembled into systems to determine total costs for the production of timber, logging residues, and whole-tree biomass.

In most cases, the system is full-tree (see text box 3.2), meaning the felled trees are taken to a landing to be processed. Processing could consist of removing the limbs and tops and then loading the stems onto trailers (timber harvest). The remaining biomass—limbs, tops, small and cull trees, and tree wastes (i.e., logging residues)—could then be chipped. In steep ground conditions, trees are usually processed at the stump, and only log sections or the tree bole is moved to the landing. For those systems, no biomass in the form of logging residues is recovered. The same is true of cut-to-length systems in which the felling and processing occurs at the stump and only clean, short boles of wood are extracted to the landing with no biomass recovery. Finally, in cases when whole trees are harvested for use as biomass and the merchantable timber is not sorted or removed, the full trees could be processed into smaller components such as chips or particles.

Conceptually, timber harvesting requires felling, extraction, processing, and loading functions that make up a system. Each of the functions has various alternative equipment types. Felling equipment can range from chainsaws to large-capacity, tracked swing feller-bunchers. Extraction equipment can be cable or grapple skidders, forwarders, or cable-yarding. Processing can be even more complex, occurring either at the stump or at the landing, with options that include chainsaws; various types of delimbers and buckers; and comminution machines such as grinders, hogs, and chippers. Figure 3.6 shows representative machines used in harvesting.

Text Box 3.2 | Harvest Methods

Cut-to-length: Trees are felled, delimbed, and bucked to individual product lengths directly in the stump area and then transported to the landing or roadside as log sections. In this study, only softwood species are harvested with cut-to-length methods.

Full-tree: Trees are felled and transported to the landing with the branches and top still intact. Transport to the landing is usually by skidder (cable or grapple). At the landing, the full trees are delimbed and bucked into individual products and components—sawlogs, pulpwood, limbs, and tops—or chipped as full trees.

Source: USDA Forest Service (2016).

Figure 3.6 | Machines for harvesting trees and forest residues

(Courtesy of U.S. Forest Service Southern Research Station)

In harvesting timber (e.g., merchantable sawlogs and pulpwood), the final product is usually delimbed and topped into tree-length roundwood or logs cut to specific lengths. In some cases, the pulpwood trees can be delimbed and debarked at the landing and chipped. This option is not considered in this study but could have wide application if the limbs, tops, and bark could be economically recovered for biomass. Then, if logging residues were recovered during the harvest or after the harvest of the roundwood timber, a chipper and usually another loader would be added to the timber harvest system.

The concept of integrated logging with the harvest of merchantable wood and biomass occurring at the same time is discussed in more detail in the 2011 *BT2*. Finally, if merchantable trees are not separated, and all the felled and extracted trees are used for biomass, then the system has the same machines used for timber harvest without any delimbing and bucking, but without an extra loader with the chipper. The key component in this study is that merchantable materials are assumed to be harvested as roundwood. If the logging residues are recovered, they are integrated into the system by adding a chipper and another loader. If only biomass is harvested as whole trees, then the system consists of felling, extraction, and chipping without any delimbing or bucking.

The systems are assembled specifically for the region (see text box 3.3), stand type, type of harvest (clear cut or thinning), products, harvest method, and ground slope. Regions have various systems based on the other parameters, e.g., systems for hardwood, planted softwoods, steep slopes. However, the region determines the harvest method—whether full-tree or cut-to-length. A regional logging analysis report is used primarily as the basis (Baker et al. 2013), along with professional judgments of associates. In the final analysis, 50% full-tree and 50% cut-to-length systems are assumed for the Inland West and North Central regions. The other regions are assumed to be 100% full-tree. In effect, the use of cut-to-length systems reduces the available logging residues by

Text Box 3.3 | Harvest Regions

Harvest costs are determined for five geographical regions of the United States (excluding Alaska and Hawaii). These regions, although not definitive in the inclusion/exclusion of specific states, were chosen to represent the types of stand or ground conditions. The five regions used in this study are similar to those reported by Johnson, Lippke, and Oneil (2012). The regions and states are listed in table 3.5.

approximately half, since it is assumed that the logging residues behind cut-to-length operations stay in the woods. Cable-yarding is included only on slopes greater than 40% and predominately in the Inland West and the Pacific Northwest regions. As with cut-to-length systems, no logging residues are harvested.

Using the literature and the professional opinions of associates, individual machines also are assembled for each region, stand type, type of cut, product, method, and slope. The type of equipment used in a particular system is based on the region and the stand type (Baker et al. 2013; Johnson, Lippke, and Oneil 2012; Wang, Hartley, and Liu 2013). For example, in the Northeast, most hardwood is still felled and delimbed with chainsaws (Wang, Hartley, and Liu 2013). This is also true of hardwoods and conifers in the Pacific Northwest. Larger feller-bunchers, skidders, cable-yarders, and loaders are used more for clear cutting than for thinning. Tracked swing feller-bunchers are used on hardwood stand types in lieu of chainsaw felling in the South, as reported.

Much effort went into equipment selection for a harvest system. The details are not reported in this section but will be reported in an ancillary paper in the near future. Since there are numerous types of machines and variations of systems, the systems used in this study are considered to be representative only of the various systems used across the United States or even in specific regions or stand types. The systems are aligned with states (see table 3.5) as a representative system, but the use does not infer that the system used is the only system in that state or the best representative of harvest systems in that state.

Table 3.5 | States in Forest Regions

Northeast	South	North Central	Inland West	Pacific Northwest
CT	AL	IA	AZ	CA
DE	AR	IL	CO	OR
KY	FL	IN	ID	WA
MA	GA	KS	MT	HI
MD	LA	MI	NM	AK
ME	MS	MN	NV	
NH	NC	MO	UT	
NJ	SC	ND	WY	
NY	TX	NE		
PA	VA	OK		
RI		OH		
TN		SD		
VT		WI		
WV				

Note: Alaska and Hawaii are not in the model.

3.2.3 Harvest Costs

A cost per dry ton is estimated for each component, and then the system cost is derived by summing these component costs. The model uses these systems to "seed" the economic analysis; therefore, the absolute costs are not as important as the relative differences. Care is taken to ensure consistency in underlying assumptions to generate the costs.

The CORRIM database is used to develop the systems and the costs per ton of the merchantable products and the biomass (Johnson, Lippke, and Oneil 2012). The database includes equipment cost, labor costs, and production levels (ton/hour) for a specific machine. These estimates cover a range of years, as the database is a composite of many published reports. The machine and machine costs are updated to a 2014 basis. The productivity levels are not changed, except for being crossed-checked as needed because of the appearance of outlier values.

The equipment costs are updated to 2014 using the producer price index for construction machinery manufacturing (Bureau of Labor Statistics 2015a). The costs had been last updated in 2004, so a multiplier is used to update the costs to a 2014 basis. All aspects of machine costs are included in these estimates—owning, operating, and fuel costs.

Logging wages are updated separately for each state and then averaged by region. The data are from the Bureau of Labor Statistics (2015b) for logging wages (North American Industry Classification System code 1133). A 35% loading factor for benefits and other payroll costs is added to the wage costs.

Two other modifications to the CORRIM costs are made: (1) adding part of the felling, extraction, and preprocessing (delimbing and bucking) to the logging residue costs and (2) adding an overhead cost. In earlier versions of this report, an assumption was that logging residues were integrated into the system and brought to the landing as part of the timber harvest. The working assumption had been that there were no costs for logging residues except for the chipping costs. All the costs for felling, extracting, delimbing, bucking, and loading were allocated to the timber, and none of these costs were allocated to the logging residues (Jernigan et al. 2013). That assumption is changed in *BT16* to allocate 10% of the timber harvest cost to the logging residues, in addition to the entire chipper and second loader costs.

Since no commercial timber products are recovered in whole-tree biomass harvest systems, all the felling, extracting, and chipping costs are allocated to the biomass costs. There are no timber delimbing and bucking costs, but a loader is also included to handle the biomass around the chipper.

Finally, there are overhead costs associated with a harvest system (e.g., a foreman, profit, tools and support equipment, and fueling systems). For this study, 15% of the total system cost is added to the total cost to cover these overhead costs. It is assumed that this added cost also covers the cost of BMP treatments, such as bridge and stream crossings, deconstruction of roads, and establishment of grass protection zones.

3.3 Projections of Wood Fuel Feedstock Supplies from U.S. Forests under Six Demand Scenarios

3.3.1 Introduction

The previous Billion-Ton reports, *BTS* and *BT2*, (Perlack et al. 2005; DOE 2011; Turhollow et al. 2014) estimate potential wood availability for a given price through 2030, but they do not consider competition for wood with conventional products such as lumber, paper and panels. We evaluate the use of small-diameter roundwood (softwood less than 9 inches in diameter at breast height [dbh] and hardwood less than 11 inches dbh) that is being harvested to supply wood biomass feedstocks in conjunction with conventional products; our analysis accounts for changes in standing timber inventories, net growth, and investment in tree plantations. Because small roundwood is (1) sold in a competitive market and used for paper and panel manufacturing and (2) harvested in conjunction with sawlogs that are used for lumber and plywood, the conventional and wood energy markets are linked and are modeled jointly in this analysis.

To incorporate wood energy markets into conventional wood products markets, this study develops six projection scenarios: a baseline scenario and five alternate scenarios that include three levels of increased national wood energy demand, two levels of increased housing starts (which lead to increased solid wood products demand), and increased intensity of forest plantation management (to meet high wood energy demand). The projections are made to 2040. For each scenario, we estimate wood fuel feedstock supply and conventional timber supply by U.S. region (North, South, and West) and source (logging residues, mill residues, small roundwood, large roundwood, and fuelwood) to meet national wood energy and conventional wood product demands.

The USFPM/GFPM (Ince et al. 2011a) is used to project wood energy supply and prices along with production, net imports, and prices for other wood products. To better project the impacts of increased wood energy demands on southern forests, a model is developed that combines the market projections of USFPM/GFPM with the forest inventory projections of the SRTS model (Abt, Cubbage, and Abt 2009). This combined model provides projections of regional wood fuel feedstock production and timber use in conventional products that are used in subsequent modeling efforts to estimate wood fuel feedstock supply by U.S. county (section 3.4).

This section discusses the wood energy and market scenarios, the USFPM/GFPM+SRTS modeling approach, and the projection results and summarizes the findings.

3.3.2 Wood Energy and Market Scenarios

Six scenarios are developed to evaluate U.S. forest product market outcomes for three levels of U.S. national wood biomass feedstocks demand, two levels of housing recovery, and two levels of southern pine plantation growth rates (table 3.6). In all scenarios, (1) U.S. demand for solid wood products is driven by projected growth trends in U.S. real gross domestic product (GDP) and single-family housing and (2) U.S. demand for paper products is driven by U.S. real GDP and by recent historical growth rates for advertising expenditures in print media and electronic media (Ince et al. 2011b). Net exports of U.S. forest products are influenced by projections of global demand for forest products and projections of global currency exchange rates. All scenarios used the 2012 USDA Economic Research Service global projections for GDP and currency exchange rates for all countries to 2030 (USDA-ERS 2015).

The baseline scenario in this study is derived from a baseline scenario developed by Ince and Nepal (2012) that assumes a moderate rebound in housing, with average single-family housing starts increasing to the long-run historical trend of 1.09 million per year by 2020 and following a slowly increasing trend thereafter (Ince and Nepal 2012). The baseline scenario also includes wood energy demand, which is determined by historical econometric relationships between fuelwood consumption and GDP growth (Simangunsong and Buongiorno 2001). In the baseline scenario, wood energy demand increases by about 26% between 2010 and 2040, from 58 to 73 million dry short tons. This scenario also includes a pine plantation growth rate determined from the most recent FIA data (USDA Forest Service 2015b).

The alternate scenarios vary with housing starts, wood energy demand, and pine plantation growth rates, as shown in table 3.6 and discussed in the following paragraphs.

Housing starts: For baseline housing starts, we assume a return to the long-term average of 1.09 million single family starts per year by 2020 as presented in Ince and Nepal (2012), then an increase of 0.4% per year after that. To generate a higher number of housing starts, we assume starts would be 10% higher by 2025 and would stay 10% higher throughout the projection. The top quartile of housing starts from 1959 to 2011 is at least 10% above the long-term average, indicating that a higher rate is achievable.

Wood energy: The baseline wood energy demand scenario is derived as shown in table 3.6. The moderate and high wood energy demand scenarios are assumed to represent increases in domestic and/or pellet export wood energy demands that are not captured in the estimated relationship between fuel wood use and GDP (fig. 3.7). Potential uses include the rapidly growing production of wood pellets for export (Abt et al. 2014). The moderate wood energy demand scenario is developed as a quadratic demand that encompasses the announced production facilities in the Forisk Consulting wood energy database through 2020 (Forisk Consulting 2014) and an assumed increase based on continued pellet exports. This results in a total wood energy demand in the moderate scenarios of 108 million dry short tons in 2040. The high wood energy demand scenario assumes that production in 2020 will be twice as high as in the moderate scenario. After fitting a quadratic through the 2015 and higher 2020 points, we end with a demand of 143 million dry short tons.

Pine plantation growth rates: The two high-demand wood energy scenarios are combined with the two housing scenarios, and both include an assumption that a timber supply response occurs from increased timber demand for use in conventional products or energy. We model this supply response by increasing the growth rates on new pine plantations in the South by 50%, which could occur from increased use of selected genetic stocks and/or best practices for plantation management. Recent research implies that under specialized conditions, growth rates could be two to five times higher than current levels (Fox, Jokela, and Allen 2007; Jokela, Martin, and Vogel 2010). We apply the 50% increase only on new plantations—well within the potential range identified in Fox and Jokela. In all other scenarios, the plantation growth rate is based on growth rates from the latest FIA data (USDA Forest Service 2015b).

Table 3.6 | Description of Wood Energy, Housing, and Plantation Investment Scenarios

Scenario[a]	Growth in housing starts[b]	Growth in wood biomass demand for energy[c]	New plantation management intensity in the South[d]
Moderate housing–low wood energy (baseline)	Returns to long-term average by 2025	Increases by 26% by 2040	Based on current FIA pine plantation growth rate
High housing–low wood energy	Adds 10% to baseline in 2025 and beyond	Increases by 26% by 2040	Based on current FIA pine plantation growth rate
Moderate housing–moderate wood energy	Returns to long-term average by 2025	Increases by 86% by 2040	Based on current FIA pine plantation growth rate
High housing–moderate wood energy	Adds 10% to baseline in 2025 and beyond	Increases by 86% by 2040	Based on current FIA pine plantation growth rate
Moderate housing–high wood energy (and high plantation growth)	Returns to long-term average by 2025	Increases by 150% by 2040	Increases by 50% over current FIA growth rate by 2040
High housing–high wood energy (and high plantation growth)	Adds 10% to baseline in 2025 and beyond	Increases by 150% by 2040	Increases by 50% over current FIA growth rate by 2040

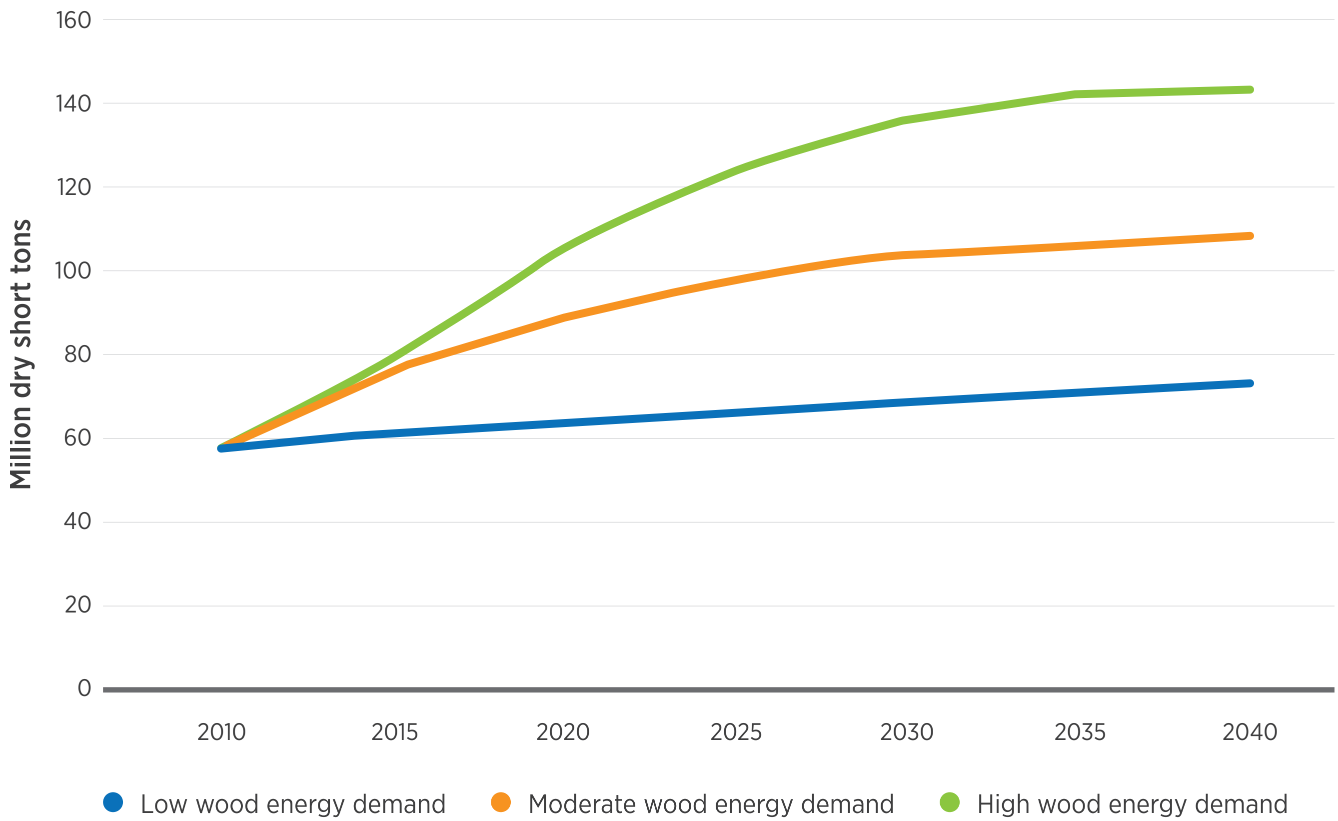
[a] All changes are to domestic production; assumptions regarding international trade are not varied from Ince and Nepal (2012); demand for paper and paperboard is consistent with Ince and Nepal (2012) assumptions.

[b] The long-term average of housing starts from 1959 through 2011 is slightly less than 1.1 million per year.

[c] Actual wood biomass production in 2010 was 58.2 million dry tons for all scenarios.

[d] Current average FIA growth rate on pine plantations across the South (all owners, all ages) is approximately 108 cubic feet/acre per year (1.6 dry ton/acre per year). Increasing management intensity by 50% only on new plantations results in an increase in the average South-wide growth rate over time up to 140 cubic feet/ac per year in 2040 (2.1 dry tons/acre per year).

Figure 3.7 | Assumed U.S. wood energy demands



3.3.3 USFPM/GFPM+SRTS Modeling Approach

The USFPM/GFPM is a global forest products partial equilibrium market model with detailed U.S. forest products production, trade, and prices. In USFPM/GFPM+SRTS, wood energy demand can compete for supply sources also used to make lumber, panels, and paper; forest inventory responds to harvest and growth; and timber prices drive timberland area in the South. U.S. demand for wood energy is specified in the USFPM/GFPM at the national level, and the model determines the fuel feedstock supply allocation among the North, South, and West regions by using the lowest-cost feedstock sources to meet the national demand. The U.S. demand for wood energy includes demands for residential and industrial fuel wood, as well as the potential for increased demand for wood pellets for export and/or assumed domestic demands for biopower and biofuels.

SRTS is used to project southern forest timber inventory as driven by timber harvests projected by USFPM/GFPM. In addition, SRTS provides estimates of timberland area in response to increases in projected timber prices. Timber inventory modeling in SRTS is done at the FIA survey unit level (or an area with a similar amount of timberland) because the FIA data used are statistically reliable only at that level of disaggregation. For the North and West, an endogenous timber inventory model (Nepal et al. 2012) and exogenous timberland area change (Ince and Nepal 2012) are used.

Two iterative procedures are used to develop projections from USPFM/GFPM and SRTS. The first iterative procedure matches SRTS projections of softwood sawtimber prices for the South with price projections from USFPM/GFPM. To do so, SRTS uses the USFPM/GFPM projected southern timber harvests for each scenario as a fixed exogenous harvest quantity. Projected timber prices from the SRTS run are compared with those from USFPM. Adjustments are then made to (1) SRTS timber supply price elasticities and (2) SRTS cull factors, which indicate what proportion of hardwood and softwood sawtimber harvest qualifies as small roundwood. SRTS is then rerun using the same harvest as before. This process is repeated until SRTS-projected softwood sawtimber prices matches projected prices from USFPM.

The second iterative procedure matches USFPM/GFPM harvest and inventory for the South to SRTS harvest and inventory. To develop a match, timber harvest projections from USFPM/GFPM are used in SRTS runs, and the resulting timber inventory from SRTS is used in the subsequent run of USFPM/GFPM as a shifter in the timber supply curves. The timber supply elasticity with respect to inventory is 1.0 for all products and species. This iterative procedure is continued until the projected timber harvest quantities from the USPFM/GFPM and the southern timber inventory quantities from SRTS do not change. At this point, the two models are considered to have converged and the modeling is considered complete for that scenario.

USFPM/GFPM projections use an exogenous national demand for fuel feedstocks to be used for wood energy. The feedstocks can be used to produce residential heat, industrial heat and power, commercial heat, electricity, biofuels, and wood pellets for export. The timber inputs that contribute to these feedstocks include logging residues, mill residues (used to generate on-site power or sold to others for power), small roundwood that can also be used to make paper and panels, and fuel wood. Both fuel wood and logging residues may be left on-site after a harvest if they are more expensive than other sources of fuel feedstocks.

The USFPM/GFPM model linked to SRTS provides projections of regional (1) timber supply for use in conventional wood products such as lumber, panels and paper products; (2) wood fuel feedstock supply by source (logging residue, mill residue, pulpwood, fuelwood); and (3) timber inventory.

3.3.4 Projection Results

Projected solid wood product consumption and wood fuel feedstock sources and prices are generally consistent with expectations based on assumptions about demand drivers and costs for supply sources in the models. For example, higher housing starts lead to higher softwood sawtimber harvest; higher wood energy demand leads to higher softwood non-sawtimber harvest; the South continues to provide the majority of wood used for energy; logging residue use increases with increased wood energy demand; and paper and paperboard production is lower with increased wood energy demand. This section presents a few highlights of the results of the six scenario projections. Additional model outputs and tables can be found online in the Bioenergy KDF.

As shown in figure 3.8*A* and *B*, higher numbers of housing starts lead to higher softwood sawtimber harvest in all scenarios. In addition, more housing starts also lead to higher softwood non-sawtimber harvests in response to increased demand for oriented strand board, as this production more than doubles over the projection period (fig. 3.8*B*). These increased harvests lead to increased prices and reduced timber inventory relative to the baseline, except under the high wood energy demand and high plantation growth rate scenarios, in which additional tree growth in the South begins to bring inventory back up to the baseline levels. Figure 3.8 also shows that increased wood energy demand results in slightly higher sawtimber and non-sawtimber harvest.

Figure 3.8 | Projected U.S. softwood harvest by scenario, 2015–2040. *A*, softwood timber. *B*, softwood non-saw timber (includes small roundwood and non-growing stock).

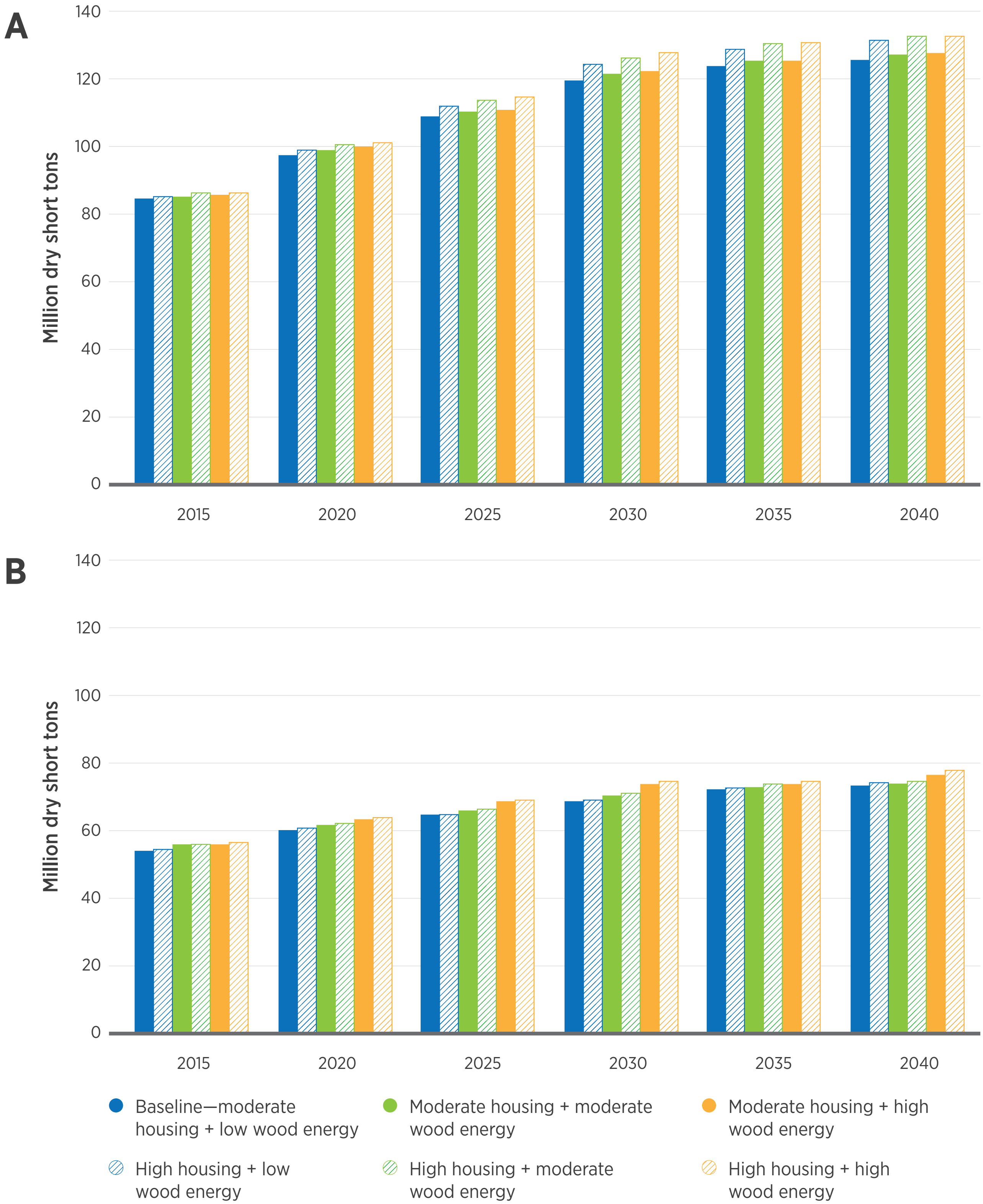
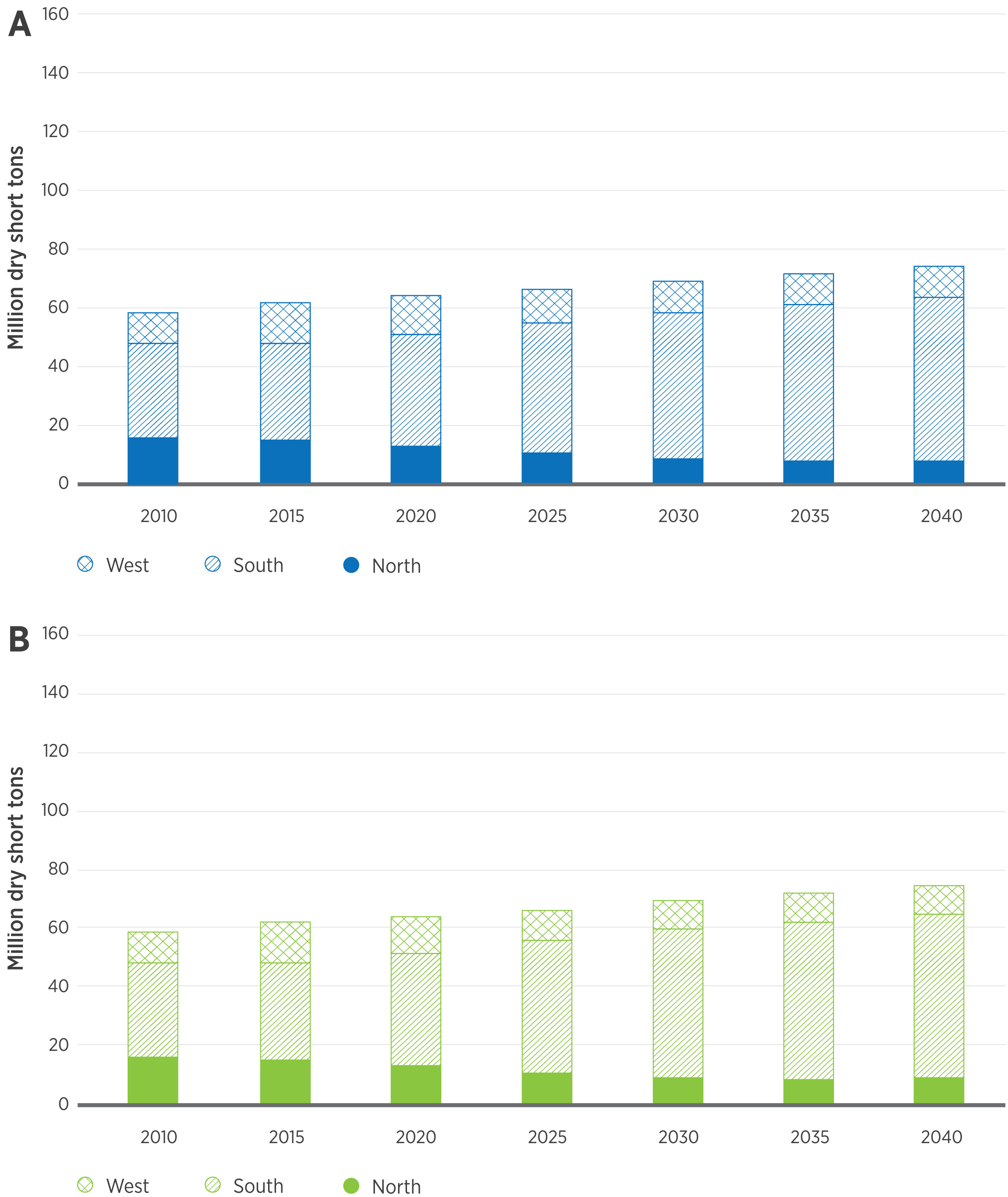


Figure 3.9*A*, *B*, and *C* show the source regions for the wood supplied for energy for a moderate housing recovery paired with low (baseline, moderate, and high demands for wood energy. In all three cases, the South continues to provide most of the wood for energy use, with the proportion increasing in the higher wood energy demand scenarios; starting at 55% in 2010, the South supplies more than 68% of wood for energy by 2040 in all six scenarios.

These aggregate outcomes obscure some of the detailed production trends. For example, there is a projected minor shift for U.S. small roundwood from conventional uses for paper or panels to use for wood energy under the higher wood energy demand scenarios (figs. 3.10 and 3.11). As some portion of small roundwood is used for wood energy in the moderate and high wood energy demand scenarios, less is available for the production of wood pulp for use in paper production; as a result, production of paper and paperboard is lower than the baseline (fig. 3.12). In the baseline or low wood energy demand scenario, paper and paperboard production increases by less than 550 thousand dry short tons from 2010 to 2040 (about 1%), which represents a slight recovery from the recession and then a decline that continues the previous historical trend. Adding additional wood energy demands leads to declines of 1% in the moderate wood energy demand scenario (a loss of about 300 thousand dry short tons of production compared with 2010) and 3% in the high wood energy demand scenario (a loss of about 1.2 million dry short tons of production compared with 2010). Newsprint production is least affected, as it uses recycled paper as a major input. The largest reduction occurs in other paper and paperboard, followed by printing and writing paper. Northern and western paper production is affected more than southern paper production, and the increase in housing starts has little impact on paper production.

Figure 3.9 | Projected U.S. wood energy production by region for low (*A*), moderate (*B*), and high (*C*) wood energy demand scenarios paired with moderate housing demand



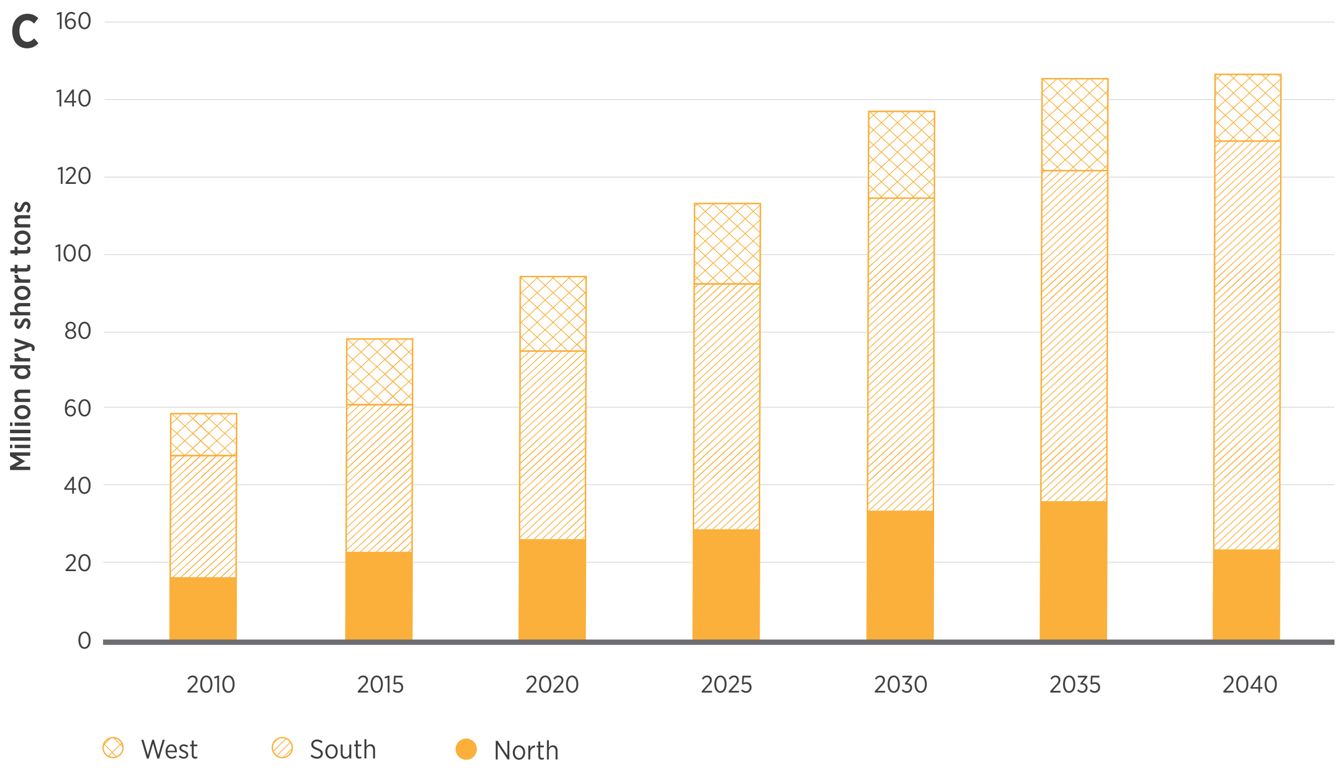


Figure 3.10 | Projected U.S. small roundwood production for use in conventional wood products, including use for pulp and paper products, paperboard and panels, by scenario, 2015–2040

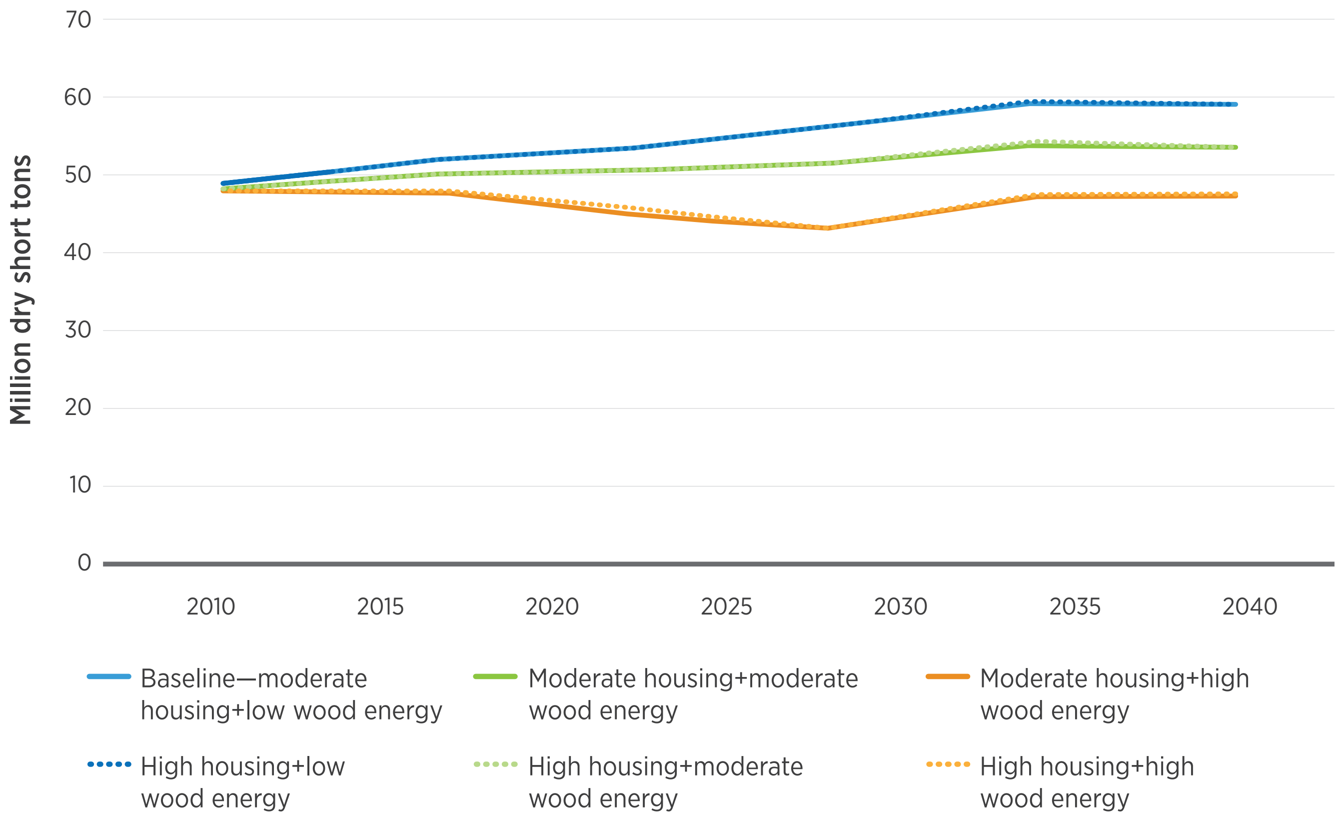
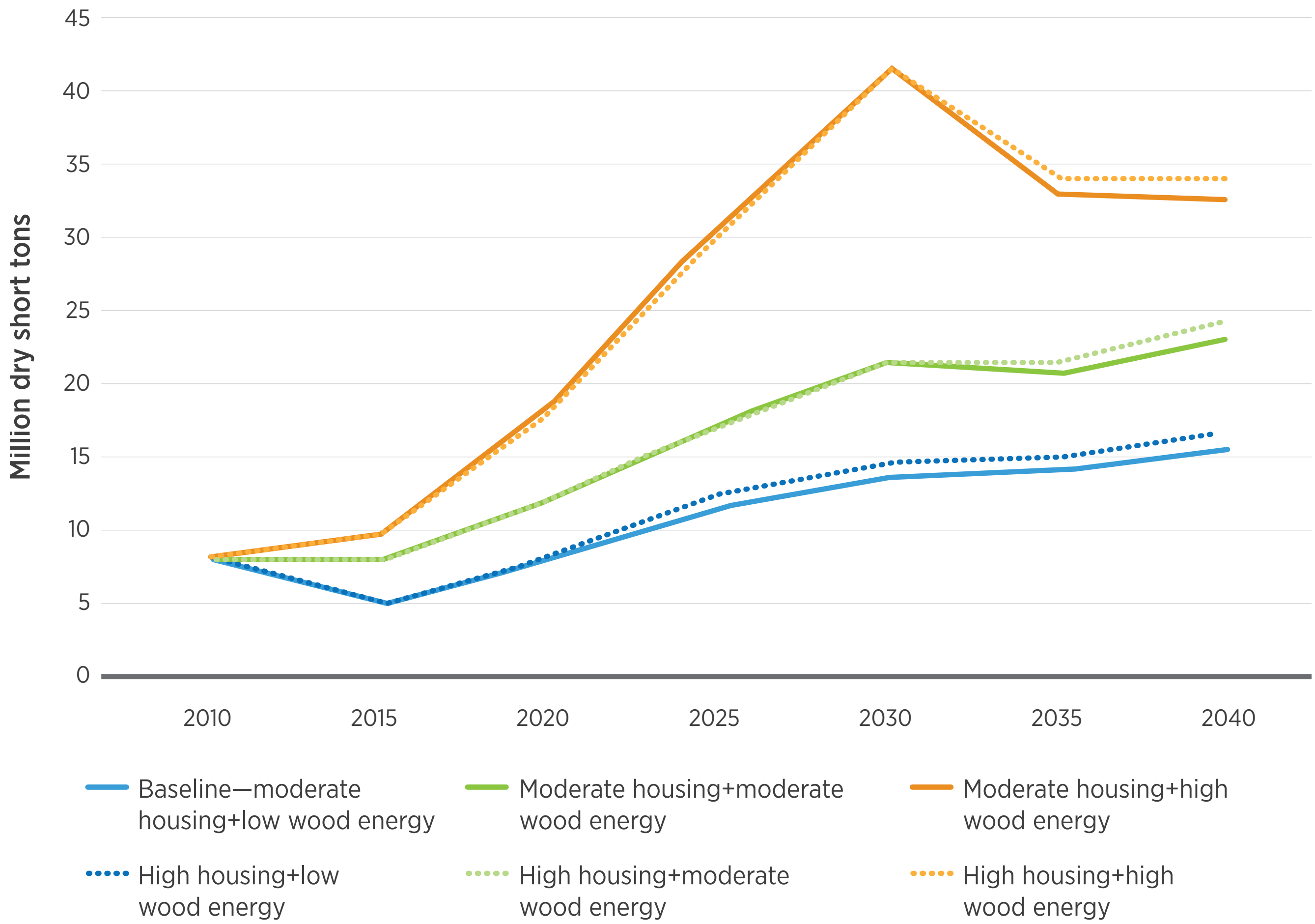


Figure 3.11 | Projected U.S. small roundwood production for wood energy use by scenario, 2015–2040

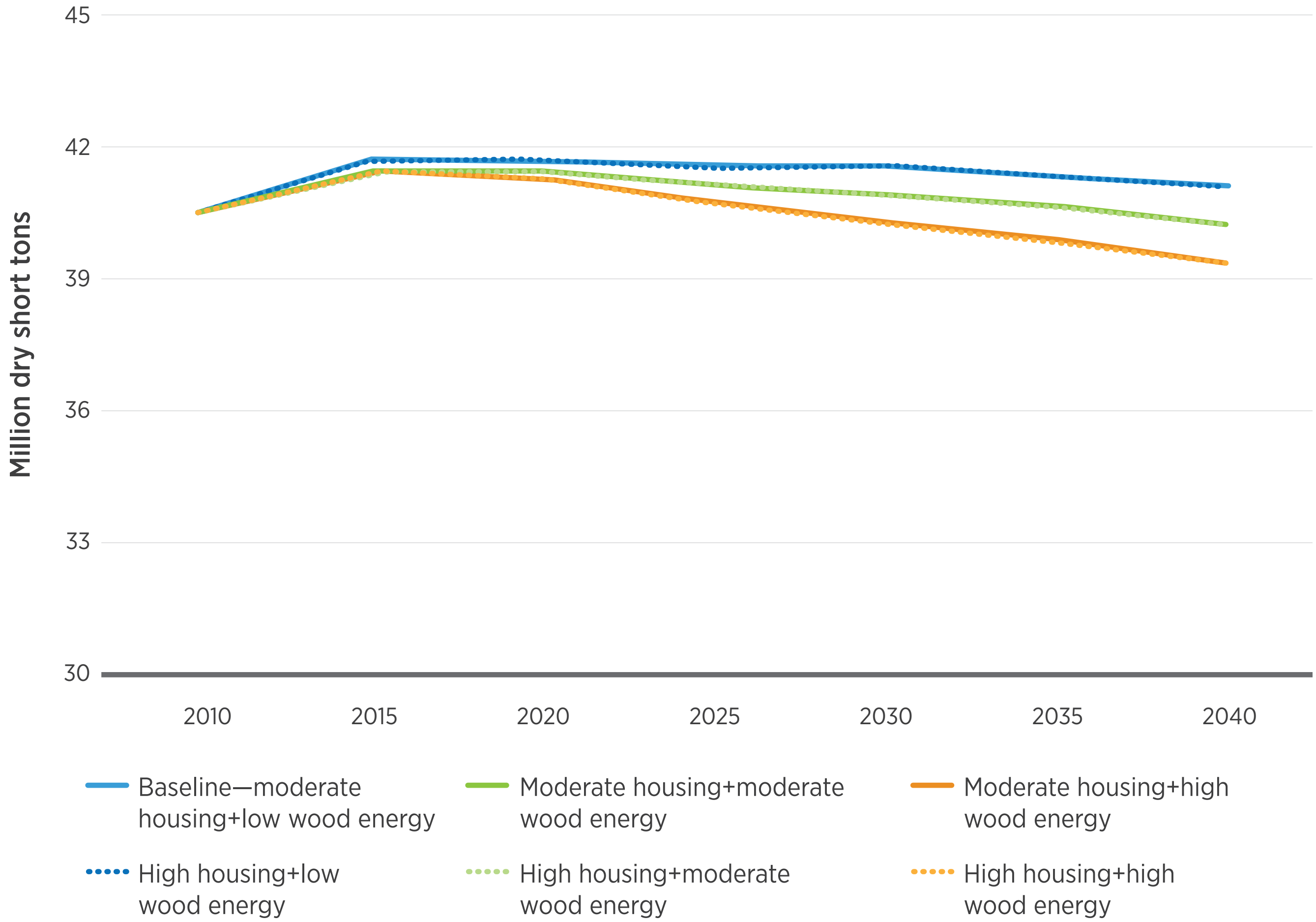


In addition to the shift of small roundwood to wood energy, the higher wood energy demand scenarios use higher amounts of logging residues as feedstocks. As the demand for wood energy and the supply of fuel feedstock increase, the proportion of feedstock from logging residues increases. This increase is due to relatively lower costs for logging residue versus other feedstocks at higher levels of demand (fig. 3.13). In 2015, few logging residues are used for wood energy because of the (relatively) high cost of procurement. As demand increases, however, logging residues begin to fulfill more of the demand for wood biomass feedstocks. By 2040, logging residue inputs to wood energy are greater than the small roundwood inputs in both the moderate and high wood energy demand scenarios.

3.3.5 Summary

This study investigates the impacts on the U.S. forest sector of scenarios projecting moderate and high growth in U.S. single family housing starts, and low

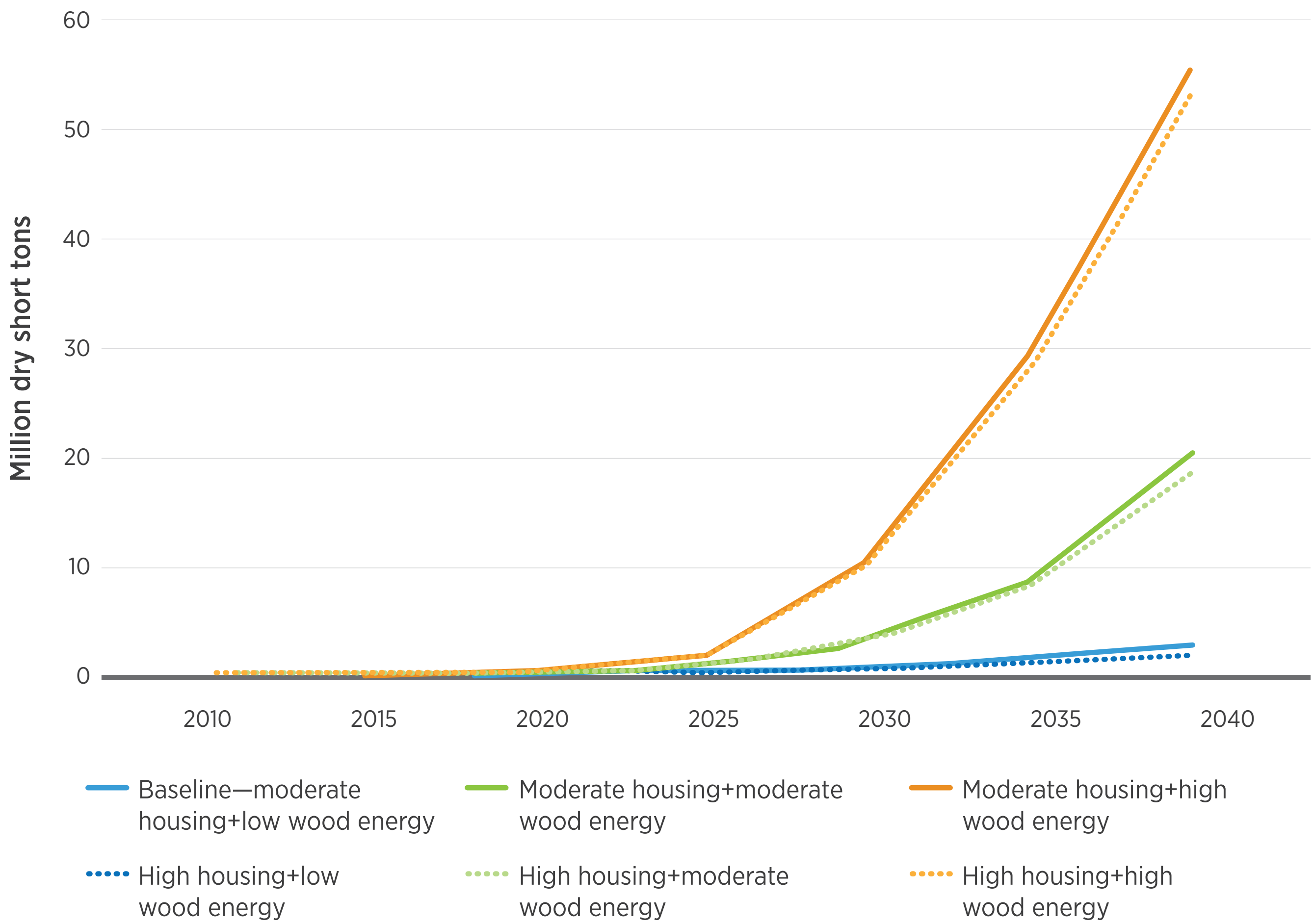
Figure 3.12 | Projected U.S. paper and paperboard production by scenario, 2015–2040



Note: Vertical axis does not extend to 0 to highlight scenario differences.

and moderate growth in wood energy demands. In addition, we model a high wood energy demand scenario, coupled with a timber supply response that involves increased growth rates on pine plantations in the South, presumably spurred by the increased wood energy demands. The low wood energy demand scenario reflects an assumed increase in wood energy, linked historically to increases in GDP, and results in an increase in demand of 53 million dry short tons by 2040. Moderate and high wood energy demand scenarios (an additional 125 and 250 million dry short tons, respectively, over the baseline in 2040) represents potential demand that could occur because of increases in either domestic or international use of wood for energy.

Figure 3.13 | Projected U.S. logging residue use for wood energy by scenario, 2015–2040



The USFPM/GFPM+SRTS modeling framework was designed to allow for competition in wood product markets. The results of the projections show tradeoffs among fuel feedstock sources (logging residues, fuelwood, mill residues, and small roundwood) and between end uses (wood energy and conventional wood products). The analysis focuses on understanding the impacts of a combination of housing starts, wood energy demands, and plantation growth on timber harvest, timber growth and inventory, timber prices, and competition for wood biomass between conventional uses (e.g., production of lumber, panels, papers) and wood energy use.

The results show that the U.S. timber harvest increases in response to increased housing starts and increased wood energy demand, affecting product prices, biological forest growth, and increased pine plantation area in the South. Because of assumed relationships between increasing softwood sawtimber prices and timberland area in the South, all scenarios show timberland area changing as sawtimber prices change, offsetting some of the inventory loss due to increased harvests over the baseline. The demand for wood energy competes with the demand for wood for conventional products such as lumber, panels, and paper. Increased wood energy demand coupled with increased housing demand raises both fuel feedstock prices and small roundwood prices, making both recovery of logging residues and the diversion of mill fiber residues and roundwood pulpwood to wood energy use economically feasible. Most of the logging residues and small roundwood needed to meet the increased wood energy demand come from the South. Because of increased competition for small roundwood, the projected production of paper and paperboard declines more under the moderate and higher wood energy demand scenarios than under the low wood energy demand scenario (baseline).

The USFPM/GFPM+SRTS modeling framework uses the latest available information on timber productivity and costs of production for each of the wood inputs and assumes that current market structures will continue through 2040. Most of the structural relationships are based on historical relationships as derived through statistical modeling. Thus, the outcomes of the projections provide consistent and reproducible results that can be used to compare policy alternatives or "what if" scenarios, but we do not assess the probability that any of these scenarios would occur.

3.4 Biomass from U.S. Timberland Using the Forest Sustainable and Economic Analysis Model

3.4.1 Introduction

The United States has extensive forest resources. These resources provide a number of benefits, one of which is wood fiber. This chapter provides estimates of forest biomass available at different prices from timberland in the contiguous United States. The biomass cost estimates incorporate the costs of stumpage, harvest, collection, and chipping. They represent biomass available at the roadside and its corresponding breakeven price.[3] Supply curves are developed for each county in the contiguous United States. In this analysis, biomass from forests includes forest residues from integrated forest operations and whole-tree biomass, in which both commercial and noncommercial trees are harvested for biomass. In both cases, harvests are only on forestland classified as timberland.

There are about 750 million acres of forested land in the United States. About 2/3 of these lands are classified as timberlands[4] (Oswalt et al. 2014; USDA Forest Service 2007; Smith 2014; Miles 2015; Perry 2014; Pugh 2014). According to Smith et al. (2009), the timber volume on timberland has increased by 50% since the 1950s. Most U.S. forestland is owned privately (58%) with private ownership dominating the North (74%) and South (87%). Private forests provide most (90%) of the wood and paper products. After harvest, most forestland regenerates naturally. However, 13% of the timberland is planted, mostly in the South (72%); 25% of the planted acres are located in the Pacific Northwest (Oswalt et al. 2014). These forestlands, in all likelihood, will contribute cellulosic feedstocks in the future. Timber resources are projected to be abundant enough to meet demands, especially if efficiency gains in harvesting and conversion technology continue. In a recent analysis conducted by the Forest Service (USDA Forest Service 2012), increased competition for land resources occurs in the RPA scenario; and the highest increase is in wood biomass use for energy (Bentley and Steppleton 2012).

Forest biomass is a potential biomass feedstock consisting of a combination of sources:

- Removal of a portion of logging residue that is currently generated during the harvesting of timberlands for conventional forest products

[3] Roadside price is the price a buyer pays for wood chips at a roadside in the forest before any transport and preprocessing to the end-use location.

[4] Timberland is defined as lands capable of producing 20 ft^3 per year per acre and not legally reserved from timber harvest.

- Removal of excess biomass from fuel treatment operations (reducing biomass to help forests increase fire resistance) and thinning operations designed to reduce risks and losses from catastrophic fires and improve forest health
- Whole tree removal from primarily smaller-diameter merchantable stands (i.e., pulpwood and/or small-diameter stands).

It is projected that access to biomass will come from integrated harvesting operations that provide sawlogs and pulpwood to meet existing market demand and provide biomass for energy and bioproducts. Three potential resources are not considered in this chapter (and are instead considered in chapter 5):

- Other removal residue that occurs when wood is cut during the conversion of timberland to nonforest uses and during thinning of "other forestland"[5] (non-timberland) that is conducted to improve forest health by removing excess biomass on low-productivity land
- Forest residues, mill wastes, and so forth created once the trees leave the landing
- Urban wood waste.

The processing of sawlogs, pulpwood, and veneer logs into conventional forest products generates significant quantities of bark, mill residues (coarse and fine wood), and pulping liquors, along with fuelwood used primarily in the residential and commercial sectors for space heating and by some electric utilities for power generation. These resources are not considered in this chapter.

3.4.2 Methods

The linear programming model ForSEAM was constructed to estimate forestland production over time, and its capacity to produce not only traditional forest products but also products to meet biomass feedstock demands. The model, based on earlier work (He et al. 2014), can be used to assess the quantity of biomass that might be available as biomass feedstocks and at what marginal cost. It assumes that projected traditional timber demands will be met and estimates costs, land use, and competition between lands. A cost minimization model requires both price and cost information to produce end products. It has an objective function of minimizing the total costs (harvest costs and other costs) under a production target goal in addition to land, growth, and other constraints. The cost minimization model requires harvesting and stumpage costs for removing timber products. No product price information is needed for the model; however, a production volume is required.

For each of the six scenarios, ForSEAM was run at demand levels ranging from 1 million dry tons to approximately 185 million dry tons in 1-million-dry-ton increments. The large volume of data precludes us from summarizing the results of every demand level. Instead, we selected the highest demand run that had a solution in all years of the simulation to provide a representative summary of production and harvested acreage. These were used to develop the supply curves of available biomass. Table 3.7 summarizes the demand level chosen for each scenario.

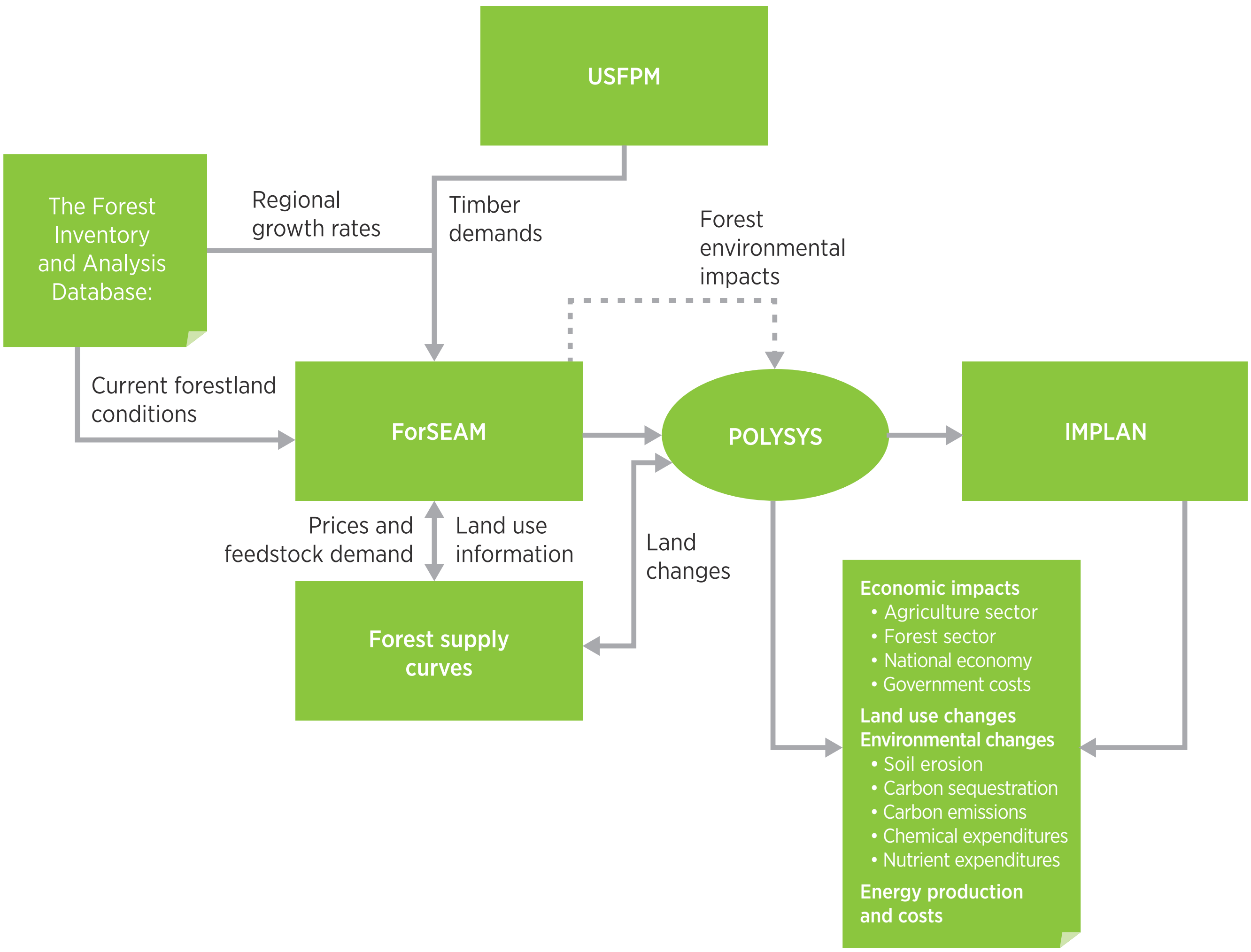
Table 3.7 | Supply Curve Demands

Scenario	Demand levels simulated	Selected demand level
	Million dry tons	
ML (baseline)	1 to 187	116
MM	1 to 184	93
MH	1 to 184	82
HL	1 to 187	117
HM	1 to 184	94
HH	1 to 184	83
HM	1 to 184	94

[5] See text box 3.1 to understand forestlands vs. timberland in the USDA Forest Service FIA database.

The remainder of this section describes the cost minimization model ForSEAM. The system of models incorporates the USFPM, ForSEAM, POLYSYS, and IMPLAN (IMpact analysis for PLANning). USFPM is used to determine what traditional forest product supplies will be required for the scenario. ForSEAM provides biomass demand and supply components from conterminous U.S. timberland (excluding Alaska and Hawaii). These supply curves can be used either in a stand-alone manner or within POLYSYS (De La Torre Ugarte and Ray 2000). POLYSYS output can then be used to determine the impacts on land use, farm sector income, and environmental indicators for soil erosion, carbon, fertilization application, and chemical application. In addition, it can be used in IMPLAN, an input-output model that estimates the impacts to the economy (fig. 3.14).

Figure 3.14 | ForSEAM modeling system



3.4.3 Mathematical Model

ForSEAM minimizes costs, subject to numerous constraints. As constructed, ForSEAM has about 30,000 decision variables and 17 constraints with a density of more than 189,000 single equations. The model minimizes the costs of traditional harvest (X,$XCTL$), harvest of whole trees for biomass (Z), and logging residue collection (U) (Eq. [1]). The choice variables (X,$XCTL$, Z, U) defined in table 3.8, along with the indexes defined in table 3.9, reflect location (i), stand type (j), average stand tree diameter (k), slope of the land the stand is on (m), method used for harvest (c), type of product that will be produced (p), and time of harvest (t). Every time the choice variable enters the solution, an acre of land is used.

$$COST_{X,XCTL,Z,U\,(t)} = \Sigma_{i=1}^{305}\Sigma_{j=1}^{5}\Sigma_{k=1}^{2}\Sigma_{m=1}^{2}\Sigma_{c=1}^{2}\left[\Sigma_{o=1}^{2} X_{i,j,k,o,m,c,p,t}\,\alpha_{i,j,k,c,t}\,(\mathrm{CL}_{i,j,o,m,c} + SC_{i,j,k}) + XCTL_{i,j,k,o=1,m,c,p,t}\,\alpha_{i,j,k,c,t}\,(\mathrm{CTL}_{i,j,m,c} + SC_{i,j,k})\right] + \Sigma_{i=1}^{305}\Sigma_{j=1}^{5}\Sigma_{k=2}^{3}\Sigma_{m=1}^{2}\Sigma_{c=1}^{2}\Sigma_{o=1}^{2}\left[\mathrm{Z}_{i,j,k,o,m,c,t}\,\beta_{i,j,k,c,t}\,(\mathrm{CW}_{i,j,o,m,c} + SC_{i,j,k})\right] + \Sigma_{i=1}^{305}\Sigma_{j=1}^{5}\Sigma_{k=1}^{2}\Sigma_{m=1}^{2}\Sigma_{c=1}^{2}\Sigma_{o=1}^{2}\left[\mathrm{U}_{i,j,k,o,m,c,t}\,\theta_{i,j,k,c,t}\,(\mathrm{CR}_{i,j,m,c} + SCR_{i,j,k})\right]$$

Table 3.8 | Descriptions of the ForSEAM Decision Variables and Coefficients

Variables and coefficients	Description
Decision variables	
XCTL $_{i,j,k,o,m,c,p,t}$	Acres of timber land harvested using cut-to-length logging option in POLYSYS region i for tree species j, stand diameter class k = 2, land slope m, and cutting option c and conventional wood product *p* at time period *t*; only on private land o = 1; there is no cut-to-length on federal timber land
X $_{i,j,k,o,m,c,p,t}$	Acres of timber land harvested to meet conventional demand for all *i, j, t, o, m, c, k* = 1, 2
Z $_{i,j,k,o,m,c,p,t}$	Acres of class 2 and class 3 whole trees harvested to meet woody biomass demand, for all *i, j, t, o, m, c, k* = 2, 3
U $_{i,j,k,o,m,c,t}$	Acres of logging residue harvested to meet woody biomass demand for all *i, j, t, o, m, c, k* = 1, 2
Right-handed sides	
A $_{i,j,k,o,m,t}$	Available acreage at time *t* for all *i, j, k, o, m,* and *t* (*acres*)
$\bar{\mathbf{G}}_{i,j,k,o,m}$	Growth (*cubic feet*) for all *i, j, k, o,* and *m*
B $_{t}$	Woody biomass targets (*dry tons*) in period *t*
D $_{s,k,p,t}$	State conventional demand for sawlogs and pulpwood for all *p, t, k* = 1, 2 (*cubic feet*)
A $_{t,j,k,o,m}$	Initial available timber acres in POLYSYS region *i* for tree species *j* and stand diameter class *k* on timber land *o* with slope *m*
Coefficients	
CR $_{i,j,o,m,c}$	Logging residue harvesting costs for thinned (*partial cut*) trees and clear-cut trees in POLYSYS region *i* for tree species *j*, ownership *o*, land slope *m*, and cutting option *c ($ per acre)*
CL $_{i,j,o,m,c}$	Log harvesting costs for thinned (*partial cut*) and clear-cut trees (*$ per dry ton*) in POLYSYS region *i* for tree species *j*, ownership *o*, land slope *m*, and cutting option *c* (*$ per acre*)
CTL $_{i,j,o,m,c}$	Logging harvest costs for cut-to-length (*$ per dry ton*) at POLYSYS region *i* for tree species *j*, ownership *o*, land slope *m*, and cutting option *c* (*$ per acre*)
CW $_{i,j,o,m,c}$	Whole tree harvesting costs for thinned (*partial cut*) and clear-cut trees (*$ per dry ton*) as developed and explained in preceding section in POLYSYS region *i* for tree species *j*, ownership *o*, land slope *m*, and cutting option *c* (*$ per acre*)
SC $_{i,j,k}$	Stumpage costs (*$ per dry ton*) of logs in POLYSYS region *i* for tree species *j*, and stand diameter class *k* (*$ per acre*)

Variables and coefficients	Description
Decision variables	
$SCR_{i,j,k}$	Stumpage costs (*$ per dry ton*) of logging residues in POLYSYS region *i* for tree species *j*, and stand diameter class *k* (*$ per acre*)
$\omega_{i,j,k}$	Percentage of timberland that can be harvested at each period in region *i* of stand species *j* and stand diameter class *k*
$\alpha_{i,j,k,c,t}$	Log yield 2015 in POLYSYS region *i* for tree species *j*, stand diameter class *k*, cutting option *c*, and time *t* (*dry tons per acre*)
$\beta_{i,j,k,c,t}$	Whole tree yield in POLYSYS region *i* for tree species *j*, stand diameter class *k*, cutting option *c*, and time *t* (*dry tons per acre*)
$\theta_{i,j,k,c,t}$	Logging residue yield in POLYSYS region *i* for tree species *j*, stand diameter class *k*, cutting option *c*, and time *t* (*dry tons per acre*)
$\Upsilon_{i,j}$	Ratio of clear cut to thinning
$\vartheta_{i,j,k,o,m}$	Annual growth in POLYSYS region *i* for tree species *j*, stand diameter class *k*, ownership *o*, land slope *m* (*dry tons per acre*)
$\upsilon_{i,j,kk,k,t}$	The inter-period stand class determination matrix from class 2 to class 1 or class 3 to class 2 at time *t*
$u_{i,j,n}$	The inter-period stand class determination matrix from class 0 (*replantation or regeneration of tree*) to class 3 at age *n* for each region *i* and tree species *j*

Table 3.9 | Indexes Used in the Model

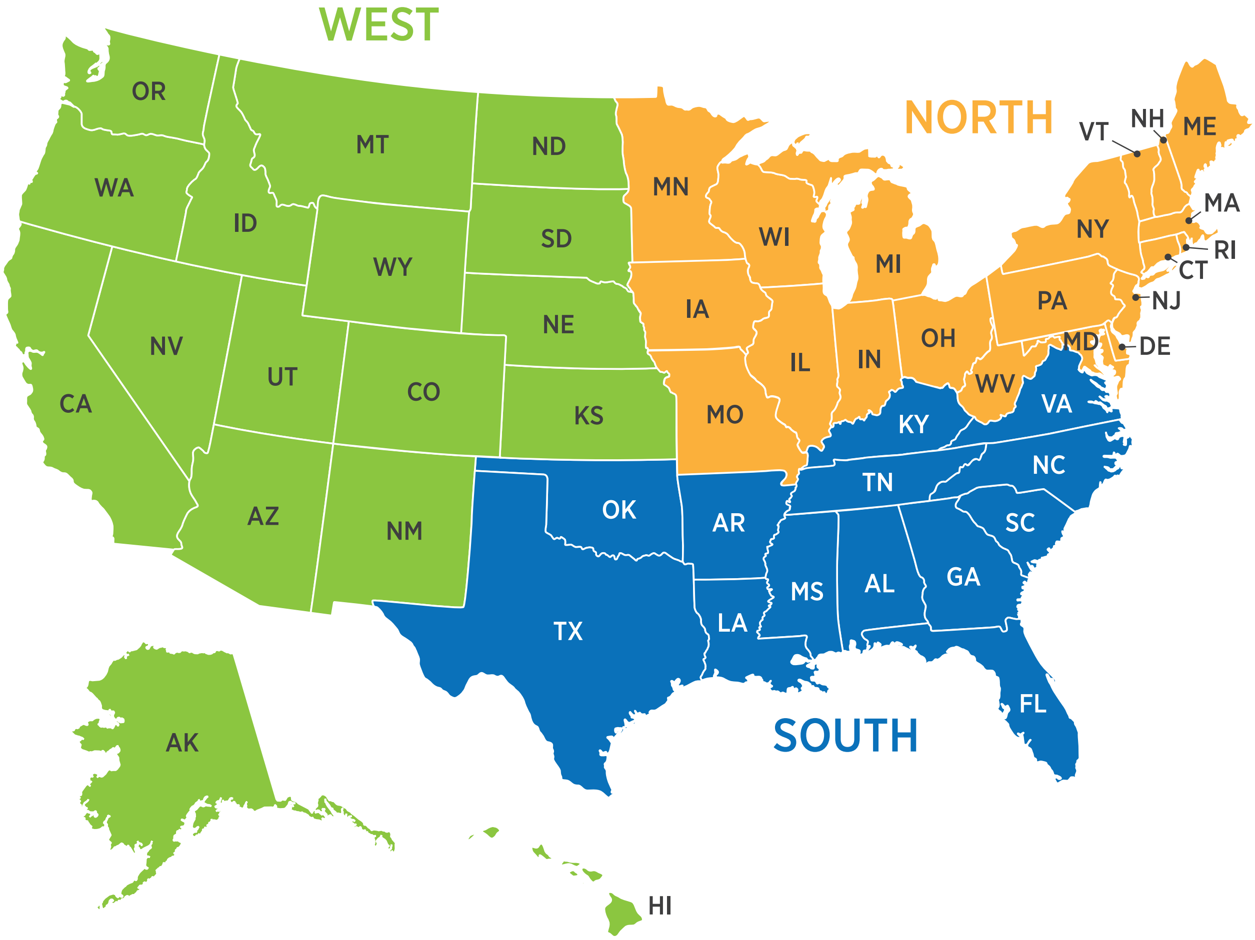
Index	Description	Magnitude
c	Cut options	*c* = 1, 2; where 1 = thinning (partial cut) and 2 = clear cut
f	Wood type	*f* = 1, 2; where 1 = hardwood and 2 = softwood
i	POLYSYS regions	*i* = 1, ... , 305
s	States	*i* = 1, ... , 48; 48 states
si	POLYSYS regions in each state	
j	Stand type	*j* = 1, ... , 5; where 1 = upper land hardwood, 2 = lowland hardwood, 3 = natural softwood, 4 = planted softwood, 5 = mixed wood
k	Stand class	*k* = 1, 2, 3; class 1 has a diameter >11 in. for hardwood and >9 in. cor softwood, class 2 has a diameter between 5 and 11 in. for hardwood and 5 and 9 in. for softwood, and class 3 has a diameter of <5 in.
o	Timberland ownership	*O* = 1, 2; where 1 = private, 2 = federal
m	Slope of land	*m* = 1, 2; where 1 = private, 2 = federal
n	The stand age calculated only for replanted or regenerated trees	*n* = 1, ... , 26
p	Conventional wood products	*p* = 1, 2; where 1 = slope $\leq$40% (LE40); 2 = slope $\geq$40% (GT40)
t	Model period	*t* = 2014, ... , 2040

The objective function is subject to a set of constraints (see equations in appendix B). The timberland constraints limit harvested timberland for conventional wood to the maximum percentage of the existing volume of class 1 land that can be harvested in any one period (Eq. [A.1]). Equations (A.2) and (A.3) constrain the harvest intensity to the existing volume of classes 2 and 3. The third timberland constraint (Eq. [A.4]) requires cut-to-length harvest acres to equal full-tree harvesting acres in the North Central region and Inland West region. The final timberland constraint (Eq. [A.5]) restricts logging residue removal (U) to those lands that provided traditional products (X). Regional constraints on thinning and clear-cut ratios are specified in Eq. (A.6).

Growth is also restricted (Eq. [A.7]). The volume of trees removed must be less than the 2014 base year harvest plus the annual growth that occurs within the state on the remaining stands. Over time, stands change. Movement of timber from small-diameter wood to pulp and sawtimber material is tracked by determining movement from one stand diameter class to another (Inter-Period Movement) through six equations ([A.8]–[A.13]).

Cost minimization models are normally driven by demand, and ForSEAM is no exception. Equations (A.14)–(A.17) require production to meet the projected demands for sawlogs and pulpwood. These demand levels are projected by USFPM for the northern, southern, and western parts of the United States (fig. 3.15). Weights are developed based on inventory to develop state estimates of demand for these traditional wood products. Equation (A.18) represents the woody biomass target for biomass feedstocks. The right hand side B_t is a national quantity for time t, and the model can iterate this variable, moving up to larger and larger supplies; or it can use a pre-specified value as projected by USFPM and the scenario being analyzed.

Table 3.15 | Three USFPM supply and production regions: North, South, and West



Source: Data from Ince et al. (2011a).

Model Solution

The model is solved in two steps:

Step 1: The model is solved for the first time period *t* (*t* = 1). In this model, neither the growth constraints (Eq. [A.7]) nor the woody biomass supply target (Eq. [A.18]) is incorporated into the model structure. The solution of *X* and *XCTL* is then used to determine the RHS of growth constraints.

$$\bar{G}_{i,j,k,o,m} = \sum_{c=1}^{2} (X^*_{i,j,k,o,m,c,p,t} + X\,CT\,L^*_{i,j,k,o=1,m,c,p,t})(\alpha_{i,j,k,o,m,c,t} + \beta_{i,j,k,o,m,c,t})$$

$\forall$ all $i,j,m,k = 1,2, t = 1$

Step 2: Then the model is solved with objective function and all the constraints. The right-hand side of Eq. (A.18) will be changed from 0 to 185 million dry tons with a 1 million ton increment to simulate the shadow values (λ_t). These shadow values hence will be used to plot the supply curve of woody biomass.

Assumptions and Input Data

This section provides in more detail all the assumptions made to use ForSEAM and the sources and levels of input data and parameters.

Geographic Definition (i)

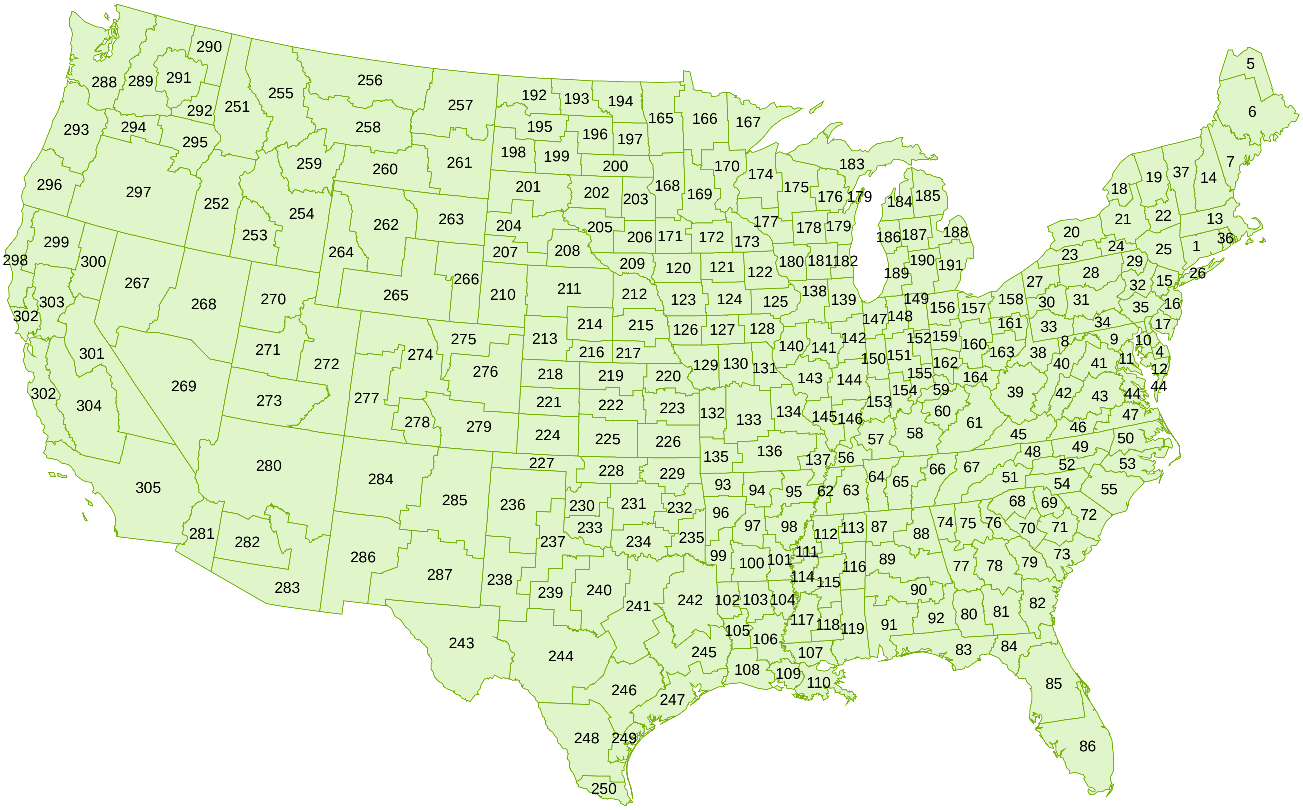
The USFPM projections are reported for three macro-regions of the United States: West, North, and South (fig. 3.15). Other data and parameters are collected and calculated for five forest regions: Northeast, South, North Central, Inland West, and Pacific Northwest (see table 3.5 for a list of states in forest regions and table 3.10 for species listings for those regions). ForSEAM is modeled and solved for 305 POLYSYS regions (fig. 3.16), which are also crop reporting districts.

Table 3.10 | Forest Regions and Forest Types

Region	Forest types
Northeast	White-Red-Jack Pine; Spruce-Fir; Maple-Beech-Birch; Oak-Hickory; Oak-Pine
South	Longleaf-Slash Pine; Loblolly-Shortleaf Pine; Oak-Pine; Oak-Hickory; Oak-Gum-Cypress
North Central	Aspen-Birch; Maple-Beech-Birch; Elm-Ash-Cottonwood; Oak-Hickory; Spruce-Fir; White-Red-Jack Pine
Inland West	Lodgepole Pine; Ponderosa Pine; Fir-Spruce; Western Hardwoods (Aspen); Chaparral; Pinyon-Juniper; Larch; Western White Pine
Pacific Northwest	Douglas Fir; Hemlock-Sitka spruce; Ponderosa Pine; Fir-Spruce; Redwood; Western Hardwoods (Scrub Oak, Alder)

Note: Forest types were identified from a map available at USDA Forest Service, Forest Inventory and Analysis National Program, http://www.fia.fs.fed.us/library/maps/.

Figure 3.16 | The 305 POLYSYS regions



Stand Species (j)

There are five stand species in ForSEAM: upland hardwood (UHW), lowland hardwood (LHW), natural softwood (NS), planted softwood (PS), and mixed wood (MIXED).

Stand Size (k)

There are three stand diameter sizes in the model:

- **Class 1:** Stands with dbh >11 inches for hardwood and >9 inches for softwood
- **Class 2:** Stands with dbh between 5 inches and 11 inches for hardwood and dbh between 5 inches and 9 inches for softwood
- **Class 3:** Stands with dbh <5 inches.

Timber Products (p)

There are five timber products from the USFPM projection (Ince and Nepal 2012; Skog 2015). The USFPM products, the corresponding ForSEAM products, and the stand sizes are presented in figure 3.17. USFPM projects demand for products including softwood sawlogs, softwood pulpwood, hardwood sawlogs, hardwood pulpwood, and other industrial roundwood. Among these products, the demands for hardwood sawlogs and other industrial roundwood are aggregated to hardwood sawlogs in ForSEAM. The fuelwood roundwood harvest is disaggregated to softwood fuelwood and hardwood fuelwood, using a ratio calculated with data from Howard, Quevedo, and Kramp (2009). In ForSEAM, sawlogs originate from class 1 stand size trees. Pulpwood originates-from trees in both class 1 and class 2 stand sizes. Biomass feedstocks are from trees in class 2 and class 3 stand sizes. The volume of UHW, LHW, and 37.5% of MIXED stand species is used in the model for hardwood timber products. The volume of NS, PS, and 62.5% of MIXED stand species is used for softwood timber products. The USFPM regional and national demand scenarios for 5-year intervals are displayed in appendix B.

Logging Methods and Options

There are four types of logging methods: (1) full-tree clear cut, (2) full-tree thinning, (3) cut-to-length clear cut, and (4) cut-to-length thinning. Descriptions of these harvest options are presented in table 3.11. The full-tree method can use the entire tree, including branches and tops. The cut-to-length method harvests logs only, leaving logging residue on the field. For both logging methods, the harvest can be clear cut or thinning. Clear cutting removes all the standing trees in a selected area. Thinning removes part of the standing trees in a selected area.

All stand classes can be harvested using full-tree clear cutting. Only class 2 stands may be harvested by clear cutting or thinning. Cut-to-length logging is used only for softwood timber in the POLYSYS North Central and Inland West regions of the country for class 1 and class 2 stands.

A proportion for clear-cut and thinning areas was applied in the West, South, and North so that a certain amount of production was guaranteed from thinning. This is because the benefits of thinning, such as increased yields and revenue, are hard to measure and capture at such a scale in the current model. With only stumpage costs and harvesting costs, the thinning option has fewer disadvantages than clear cutting because of the lower yield level per acre of timberland. Figure 3.18 shows the proportion of timberland harvested using clear cutting and thinnings (partial cutting). In the current model, we use the proportion that was used in 2006–2011. The clear-cut portion is 42%, 28%, and 10% for the West, South, and North, respectively.

Figure 3.17 | Conventional timber products in USFPM and ForSEAM

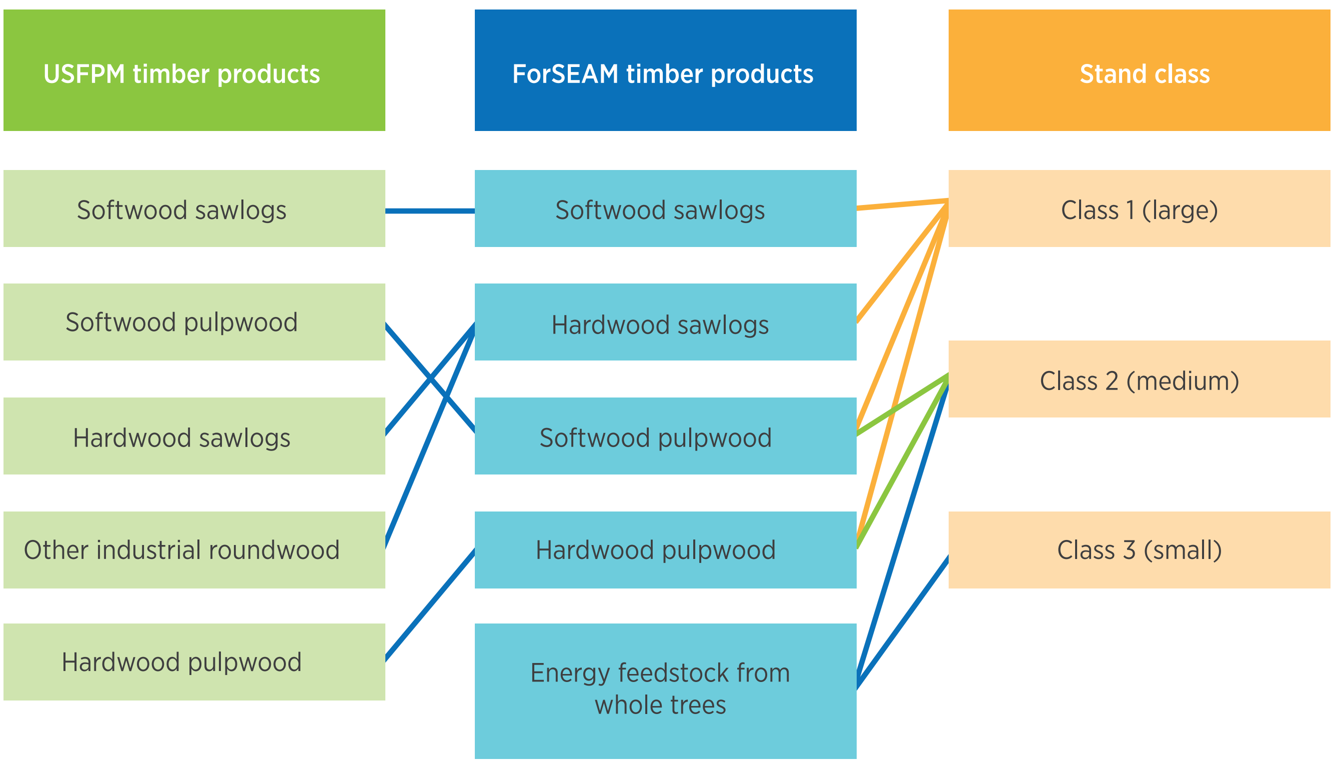
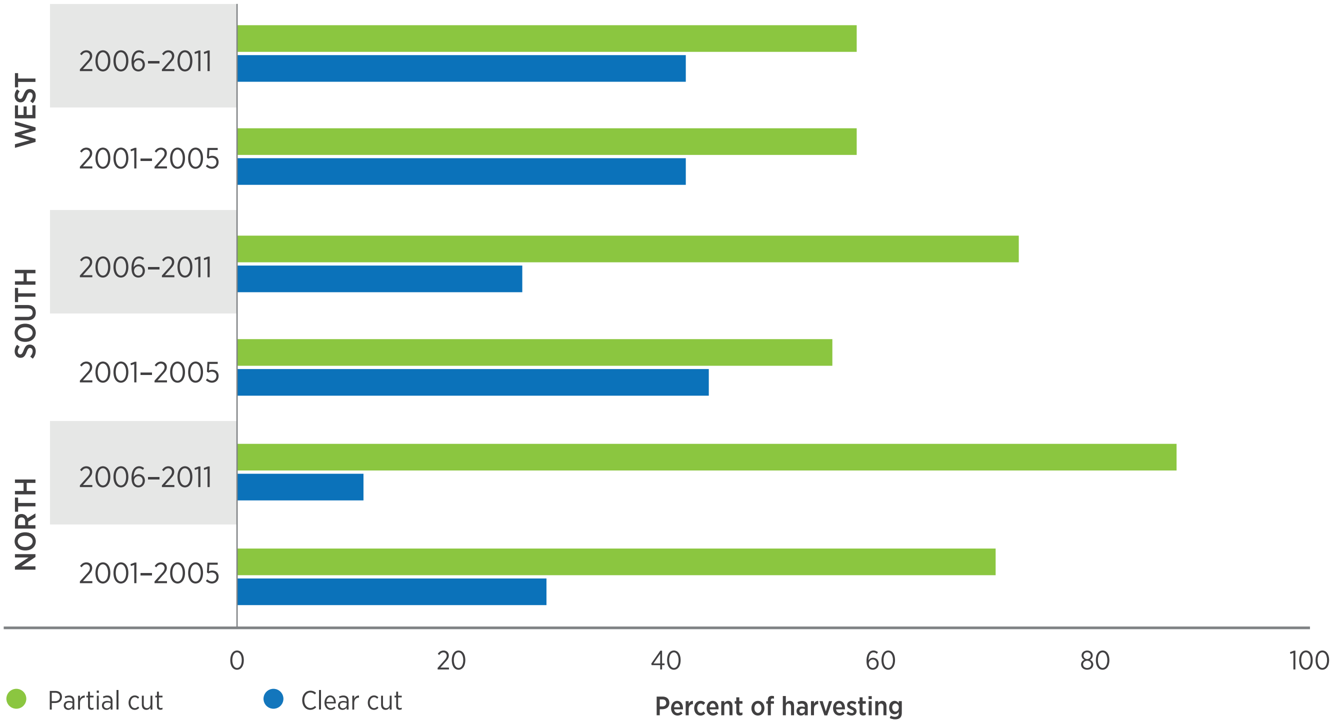


Table 3.11 | Logging Methods and Options

	Clear cut	Thinning
Full tree	1. Full-tree clear cut • Removes all the standing trees in a selected area • The entire tree can be used, including branches and tops • Class 1, class 2, and class 3 stands • All regions.	2. Full-tree thinning • Partially removes standing trees in a selected area • The entire tree can be used, including branches and tops • Class 2 stands only • All regions.
Cut-to-length	3. Cut-to-length clear cut (softwoods only) • Removes all the standing trees in a selected area • Only logs can be used, and branches and tops are left on the field • Class 1 stands only • North Central and Inland West regions only.	4. Cut-to-length thinning (softwoods only) • Partially removes standing trees in a selected area • Only logs can be used, and branches and tops are left on the field • Class 2 stands only • North Central and Inland West regions only.

Figure 3.18 | Proportion of timberland harvested in the United States by method of harvest for 2001–2005 and 2006–2011



Source: USDA Forest Service (2015b).

Timberland Area (A) and Slope (m)

There are 514 million acres of timberland in the United States (FAZ 2015), including Alaska and Hawaii. Timberland is defined as available forestland that is producing or is capable of producing crops of industrial wood. Areas qualifying as timberland have the capability to produce more than 20 ft^3 per acre annually of industrial wood in natural stands on which harvesting is not prohibited. Currently inaccessible and inoperable areas are included. ForSEAM takes into account timberland in the 48 conterminous states that is privately or federally owned and no more than a half mile from the existing road system. Data from the FIA database (2015) indicate that there are about 300 million acres of privately owned timberland and another approximately 87 million acres of federal lands (see table 3.12 and table 3.13). A total of 386 million acres of federal and private timberlands are within 0.5 miles of a road and are the available acres in the ForSEAM model under the stated assumptions; but of course, only a few million acres are harvested annually. The assumption is that timber and biomass could be harvested within that distance to a road without any road-building. No road building is a sustainability criterion built into the model that was also used in the 2011 *BT2*. Therefore, the available biomass is severely limited by several assumptions of timberland area and access, such as distance to road and land slope.

Land slope is categorized into two groups (table 3.14): (1) slope ≤40% (LE40) and (2) slope >40% (GT40). Not all stand species on timberland in slope category GT40 are available for harvesting in the model. As table 3.14 indicates, no trees in the Northeast, South, North Central, and Inland West regions in category GT40 are harvested, as the assumption is the lack of cable systems in these regions. The model assumes that only in the Pacific Northwest can trees be harvested on both LE40 and GT40 timberland; again, the assumption is for conventional timber products only, as the biomass is not extracted with cable systems on slopes in category GT40.

Table 3.12 | Acres Included in the Model by Stand Class, Slope, Ownership, and Species Type

Class	Slope	Ownership	LHW	UHW	NP	PP	MIXED	Total
			Million acres					
1	LE40	Private	35.57	59.54	29.76	14.47	9.82	149.16
		Federal	6.41	9.98	25.56	2.84	1.96	46.75
	GT40	Private	2.77	10.24	3.61	0.70	0.48	17.80
		Federal	0.66	2.19	8.41	0.72	0.10	12.07
2	LE40	Private	17.08	25.39	10.09	15.24	4.86	72.67
		Federal	2.63	5.07	4.27	1.46	0.71	14.14
	GT40	Private	0.46	2.15	0.54	0.43	0.21	3.80
		Federal	0.13	0.62	0.70	0.21	0.04	1.71
3	LE40	Private	10.75	19.52	8.60	9.32	5.28	53.48
		Federal	1.57	3.60	4.37	0.82	0.55	10.91
	GT40	Private	0.34	0.76	0.64	0.47	0.03	2.25
		Federal	0.08	0.34	0.80	0.18		1.40
Total			**78.45**	**139.40**	**97.37**	**46.87**	**24.05**	**386.14**

Note: LE40 is slope ≤40%; GT40 is slope > 40%.

Table 3.13 | Acres in the Three USFPM Regions (see regions in fig. 3.15)

Region	Diameter Class	Owner-ship	Slope	Stand types (million acres)					
				LHW	UHW	NP	PP	MIXED	Total
North	1	Private	LE40	21.06	29.89	5.59	0.72	2.32	59.59
			GT40	1.69	4.09	0.12	0.02	0.15	6.06
		Federal	LE40	4.15	5.78	1.73	0.85	0.63	13.14
			GT40	0.37	0.54	0.02	0.02	0.01	0.96
	2	Private	LE40	11.48	12.77	3.27	0.50	0.99	29.01
			GT40	0.25	0.69	0.03	0.00	0.05	1.02
		Federal	LE40	1.95	3.24	1.09	0.29	0.26	6.83
			GT40	0.07	0.12	0.00		0.00	0.20
	3	Private	LE40	5.10	6.72	2.95	0.19	0.40	15.36
			GT40	0.13	0.18	0.02		0.01	0.34
		Federal	LE40	0.93	2.22	0.90	0.17	0.17	4.39
			GT40	0.01	0.03	0.00			0.03
		Total		**47.18**	**66.26**	**15.72**	**2.76**	**4.99**	**136.92**
South	1	Private	LE40	12.61	28.09	13.43	12.04	7.48	73.65
			GT40	0.68	5.43	0.16	0.04	0.32	6.63
		Federal	LE40	1.85	3.56	4.17	0.78	1.33	11.70
			GT40	0.04	1.23	0.13		0.09	1.50
	2	Private	LE40	4.84	11.46	5.36	13.87	3.82	39.35
			GT40	0.07	1.11	0.09	0.06	0.15	1.47
		Federal	LE40	0.50	1.08	0.69	0.82	0.44	3.53
			GT40	0.01	0.19	0.01		0.04	0.25
	3	Private	LE40	5.02	12.17	3.17	7.80	4.84	33.01
			GT40	0.04	0.40	0.06	0.02	0.03	0.55
		Federal	LE40	0.48	0.85	0.44	0.32	0.38	2.47
			GT40	0.00	0.06	0.01			0.07
		Total		**26.15**	**65.65**	**27.71**	**35.75**	**18.91**	**174.17**
West	1	Private	LE40	1.90	1.56	10.73	1.71	0.02	15.92
			GT40	0.40	0.73	3.34	0.64	0.01	5.12
		Federal	LE40	0.40	0.64	19.66	1.22		21.92
			GT40	0.24	0.42	8.26	0.70		9.62
	2	Private	LE40	0.76	1.15	1.47	0.87	0.05	4.30
			GT40	0.14	0.35	0.43	0.37	0.02	1.32
		Federal	LE40	0.18	0.74	2.50	0.36	0.01	3.78
			GT40	0.06	0.31	0.69	0.21		1.27
	3	Private	LE40	0.63	0.63	2.48	1.32	0.04	5.10
			GT40	0.16	0.18	0.56	0.45		1.35
		Federal	LE40	0.16	0.53	3.03	0.33		4.06
			GT40	0.07	0.25	0.79	0.18		1.29
		Total		**5.12**	**7.49**	**53.94**	**8.35**	**0.15**	**75.05**

Table 3.14 | Timberland and Stand Species That Are Available for Harvesting in Different Regions

Region	Slope	UHW	LHW	NS	PS	MIXED
Northeast	LE40	Yes	Yes	Yes	Yes	Yes
	GT40	–	–	–	–	–
South	LE40	Yes	Yes	Yes	Yes	Yes
	GT40	–	–	–	–	–
North Central	LE40	Yes	Yes	Yes	Yes	Yes
	GT40	–	–	–	–	–
Inland West	LE40	Yes	Yes	Yes	Yes	Yes
	GT40	–	–	–	–	–
Pacific Northwest	LE40	Yes	Yes	Yes	Yes	Yes
	GT40	Yes	Yes	Yes	Yes	Yes

Note: Land in the Pacific Northwest is available for harvesting for timber products because of available cable systems in use, whereas the other regions are assumed to have limited or no cable systems available.

Yield Levels for Clear Cut, Thinning, and Annual Growth (α, β, θ, g)

In the first simulation year, yield levels (cubic feet/acre or dry ton/acre) for logging and harvesting of woody biomass using the clear-cut option are calculated using existing information on standing tree volume and corresponding timber area from the FIA database aggregated at the POLYSYS county level. The thinning yield is 70% of the clear-cut yield, assuming thinning treatment would be a thinning-from-above (Coops et al. 2009; Penn State 2016) when harvesting conventional products and only the smaller diameter trees when harvesting whole-tree biomass.

Annual growth yield (cubic feet/acre or dry ton/acre) is based on the net annual growth and the corresponding timber area. It is assumed that for each acre of a certain stand, the current yield of the simulation year is the yield level from the beginning of the simulation period, plus the total growth yield, multiplied by the total numbers of years from the beginning to the present.

Wood Harvesting Intensity (ω)

Wood harvesting intensity is an indicator of the annual felling as a percentage of the allowable cut. We first tried to obtain wood harvesting intensity from Timber Product Output (TPO) removal data divided by the standing volume of live trees in the corresponding counties. The results varied by county, by timber product (sawlogs, pulpwood, and fuelwood), and by hardwood and softwood. That method proved not to be a preferable way to obtain the ratios, because TPO has significant gaps in information for counties that have a timber acreage inventory. We decided to take the potential production quantities and compare them with the 2010 projected demand from USFPM. We found that 5% of the existing standing volume, at most, is sufficient to meet the future demand for conventional wood.

Wood harvesting intensity limits to 5% the amount of forest within a POLYSYS region that can be harvested in any one year. It limits how much acreage is actually available for harvest. The growth rate limits the volume to growth at the state level. Therefore, the model does not allow the wood harvest to exceed state growth levels within a state. The 5% figure is estimated by taking the potential production compared with the 2010 projected demand estimated by USFPM.

Logging Residue Retention

Not all available logging residues are harvested for biomass feedstock use. A retention rate of 30% is applied to residues from clear-cut full-tree harvesting on timberland with a slope of LE40. If the available logging residues are from stands located on timberland with a slope of GT40, all of the logging residues are left on the site. If the timberland is thinned (partially cut), 30% of the residues are retained on-site (i.e., a 30% retention rate) rate) if slope is GT40. If the available logging residues are from thinnings (partial-cut) stands, all residues are harvested as biomass feedstocks in the model if slope is LE30. The underlying assumption is that there will still be residues left on-site because of tree breakage and losses from harvesting trees, and that the remaining trees will provide sufficient site protection.

In the 2005 *BTS* and 2011 *BT2*, a technical recovery efficiency of 65% for residues is used in addition to the retention coefficient. Mechanical systems cannot feasibly recover more than 65% of the broken limbs, broken tops, and foliage spread across sites (Dykstra, Hartsough, and Stokes 2009). So with a 30% retention rate, in actuality 35% is retained. For this study, the technical recovery coefficient is assumed to be 70% because of system and equipment improvements. Therefore, a retention level of 30% results in a 70% technical recovery of forest residues.

Inter-Period Class Determination Matrix (v, u)

After timberland is clear cut, we assume replanting and regeneration of the land follows. We also assume that if class 2 and class 3 standing trees are not harvested, they continue to grow and became class 1 and class 2 stands, depending on the annual increment of quadratic mean diameters. We form an inter-period class determination matrix to model the change from replanting to class 3 stands, class 3 to class 2 stands, and class 2 to class 1 stands over the simulation periods. If class 2 stands are harvested with the thinning option, they are not available until they become class 1 stands. Replanting or regeneration acres are available for harvesting when the stands become class 2.

Stumpage Costs (SC, SCR)

Stumpage prices are derived using the following steps. We first obtain a pulpwood price update for 2014 based on RISI, International Wood[6] fiber report data, and calculations of stumpages.

As seen in table 3.15, data for hardwood pulpwood roundwood prices in the West region are missing. Instead, we use the 2007 data of $23.48 per dry ton for hardwood in the West, as reported in *BT2*. We used the RISI (2008) pulpwood price as the stumpage price for class 2 stands of the corresponding hardwood and softwood (table 3.16). For mixed wood, the price is calculated as 37.5% of the hardwood stumpage price plus 62.5% of the softwood stumpage price (table 3.16). For each stand species, the stumpage price of a class 1 stand is twice that of a class 2 stand. The class 3 stand stumpage price is 50% of the class 2 stand price. If logging residues are collected from the harvested site, their stumpage price is the fraction of the whole-tree stumpage price from table 3.15; it is based on the ratio of the yield from residues to the yield from a whole tree, using the FIA database to calculate that fraction.

[6] Accessed by Ken Skog, who provide updated calculations of estimated 2007 delivery cost fractions. See table 3.2 of the 2011 *BT2* (DOE 2011, 27) for more information on these calculations. Table 3.14 stumpage prices are derived from these calculations.

Table 3.15 | RISI Pulpwood Prices, Roundwood ($ per dry ton stumpage)

Region	2014			2013	
	3Q	2Q	1Q	4Q	3Q
Hardwood					
North	22	22	20	19	19
South	17	17	17	17	16
West	N/A	N/A	N/A	N/A	N/A
Softwood					
North	21	21	20	19	19
South	16	16	16	16	16
West	17	17	17	16	15

Source: Data from Skog (2015).

Table 3.16 | Stumpage Price of Conventional Wood ($ per dry ton)

Stand species	North			South			West		
	Class 1	Class 2	Class 3	Class 1	Class 2	Class 3	Class 1	Class 2	Class 3
UHW	44.00	22.00	11.00	34.00	17.00	8.50	46.96	23.48	11.74
LHW	44.00	22.00	11.00	34.00	17.00	8.5	46.96	23.48	11.74
PS	42.00	21.00	10.50	32.00	16.00	8.00	24.00	17.00	8.50
NS	42.00	21.00	10.50	32.00	16.00	8.00	24.00	17.00	8.50
MIXED	42.75	21.38	10.69	32.75	16.38	8.19	38.86	19.43	9.72

Harvesting Costs (CL, CTL, CW)

Harvesting costs are different depending on whether logging residues are retrieved when merchantable timber is harvested, or stands are harvested as whole-tree woody biomass. If only merchantable timber is harvested, the harvesting costs include felling, skidder, delimbing, and loader costs. This type of harvest occurs only on sites that are steep or when a cut-to-length harvesting option is used. If logging residues are collected as woody biomass in the integrated system with merchantable timber, extra costs are added to the timber harvest costs. A chipper and extra loader are added to the timber harvest system to make it an “integrated timber and biomass harvest system.” However, the logging residue cost is only for the added chipper and loader and, as explained in section 3.2, an apportioned 10% of the timber harvest costs.

The harvesting costs for the timber, conventional sawtimber, and pulpwood components only are shown in table 3.17. These timber costs include the 10% reductions charged to biomass (logging residues) because all harvesting, unless explicitly categorized as either cable or cut-to-length, is assumed to be integrated timber harvesting. The costs are by stand type, harvest option, cutting option, slope, and forest region. Under full-tree logging options, logging residues can be collected as woody biomass. Cut-to-length systems process the trees at the stump, which disperses the biomass across the site, whereas full-tree systems bring the limbs and tops to the roadside for processing. Although residues can be recovered after cut-to-length harvests, the option is considered to be too costly in this model. On sites in slope category GT40, only merchantable trees and logs are extracted to the roadside—biomass is not integrated into this system, and no logging residues are removed from GT40 sites. There are two reasons behind this assumption: (1) the residues are needed to protect the steep slopes, and (2) cable logging is not efficient or economical for extracting trees with limbs and tops attached. The costs of harvesting the logging residues with the timber are shown in table 3.18 as the additional cost for the added chipper and loader. As stated, these costs also include 10% of the timber harvest costs.

Costs for harvesting logging residues are presented in table 3.18, and whole-tree costs for both clear-cut and thinning harvesting are in table 3.19. The logging residues costs are region specific, whereas the whole-tree costs are applied across all regions.

Table 3.17 | Harvesting Costs for Timber Products ($ per dry ton)

Stand type	Harvest option	Cut option	North-east	South	North Central	Inland West	Pacific Northwest	
			LE40	LE40	LE40	LE40	LE40	GT40
UHW	Full tree	Thinning	31.46	29.49	31.46	31.46	31.46	41.72
		Clear cut	29.22	25.45	29.22	29.22	29.22	27.77
LHW	Full tree	Thinning	31.46	29.49	31.46	31.46	31.46	41.72
		Clear cut	25.45	25.45	25.45	25.45	25.45	27.77
NS	Full tree	Thinning	29.62	29.49	29.49	29.62	29.62	41.72
		Clear cut	24.68	24.25	24.25	24.68	24.68	27.77
	Cut-to-length	Thinning	–	–	57.03	57.03	–	–
		Clear cut	–	–	49.63	49.63	–	–
PS	Full tree	Thinning	29.22	29.22	17.05	29.62	29.62	41.72
		Clear cut	24.25	24.25	24.25	25.45	25.45	27.77
	Cut-to-length	Thinning	–	–	65.58	65.58	–	–
		Clear cut	–	–	49.63	49.63	–	–
MIXED	Full tree	Thinning	29.62	29.62	28.29	29.62	29.62	41.72
		Clear cut	24.68	24.68	23.48	25.45	25.45	27.77
	Cut-to-length	Thinning	–	–	65.58	65.58	–	–
		Clear cut	–	–	49.63	49.63	–	–

Note: All harvests on slope category GT40 are actually "tree-length" or logs, as cable yarding is used. Limbs and tops are left at the stump and only merchantable timber is extracted.

Table 3.18 | Logging Residue Harvest Costs for Integrated Harvesting ($ per dry ton)

Stand type	Cut option	North-east	South	North Central	Inland West	Pacific Northwest	
		LE40	LE40	LE40	LE40	LE40	GT40
UHW	Clear cut	14.62	14.20	14.62	14.62	14.62	14.45
	Thinning	17.30	17.08	17.30	17.30	17.30	18.44
LHW	Clear cut	14.20	14.20	14.20	14.20	14.20	14.45
	Thinning	17.30	17.08	17.30	17.30	17.30	18.44
NS	Clear cut	14.11	14.06	14.06	14.11	14.11	14.45
	Thinning	17.09	17.08	14.11	17.08	17.09	18.44
PS	Clear cut	14.06	14.06	14.06	14.20	14.20	14.45
	Thinning	17.05	17.05	17.05	17.09	17.09	18.44
MIXED	Clear cut	14.11	14.11	13.98	14.20	14.20	14.45
	Thinning	17.09	17.09	16.94	17.09	17.09	18.44

Table 3.19 | Harvesting Costs for Whole Trees as Woody Biomass ($ per dry ton)

	Clear cut	Thinning
UHW	19.85	35.92
LHW	25.21	35.92
NS	29.85	30.34
PS	29.85	35.92
MIXED	29.85	35.92

3.4.4 Results

Although six scenarios are analyzed in the model, only two scenario analyses are consistently presented in this chapter. All of the results of these scenarios and the other scenarios are available online within the Bioenergy KDF. These scenarios are developed and projected using USFPM as explained in section 3.3, with the characteristics described in table 3.20. The baseline scenario (Baseline_ML) assumes low growth in woody biomass demand for energy; moderate new plantation management intensity in the South; and moderate demand for conventional wood for housing, paper and paperboard, and exports. The high, high (HH) scenario assumes a high increase in demand both for conventional wood for housing, paper and paperboard, and exports and for woody biomass for energy.

Table 3.20 | USFPM Scenarios (see table 3.6)

Scenario name	Characteristics				
	Growth in wood biomass demand for energy	Growth in housing starts	New plantation management intensity in the South	Growth in demand for paper and paperboard	Growth in demand for biomass for energy, and wood and paper products (foreign countries)
Baseline_ML	Low	Moderate	Moderate	Moderate	Moderate
MM	Moderate	Moderate	Moderate	Moderate	Moderate
MH	High	Moderate	High	Moderate	Moderate
HL	Low	High	Moderate	Moderate	Moderate
HM	Moderate	High	Moderate	Moderate	Moderate
HH	High	High	High	Moderate	Moderate

Note: The first letter of the code for the scenarios indicates the level of housing starts (high and medium), and the second letter indicates the level of biomass harvested for fuel (high, medium, and low).

Table 3.21 | USFPM Projection of Feedstocks from Woody Biomass (million dry tons)

Scenario	2015–2019	2020–2024	2025–2029	2030–2034	2035–2039	2040
Baseline_ML	14	14	14	14	14	15
MM	21	25	29	33	34	34
MH	22	29	39	51	55	55
HL	14	14	14	14	14	15
HM	21	25	29	33	34	34
HH	22	29	38	51	54	55

The USFPM projections (from section 3.3) for woody biomass as a biomass feedstock (in million dry tons) under all six scenarios are presented in table 3.21. From 2015 to 2040, the woody biomass projection is relatively low, ranging from 14 million to 15 million dry tons in Baseline_ML, while woody biomass demand ranges from 22 million to 55 million dry tons in scenario HH. ForSEAM uses the projection as the exogenous demand level for woody biomass and solves the model at the POLYSYS level.

Table 3.22 | Acres Harvested by Feedstock Type, Stand Diameter Class, Cut Option, Ownership, Scenario, and Year at $60 per Dry Ton (P = private; F = federal)

Scenario	Year	Conventional wood (logging residues) (million acres)						Whole-tree biomass (million acres)						Total (million acres)			
		Class 1 stand		Class 2 stand				Class 2 stand				Class 3 stand					
		Clear cut		Clear cut		Thinning		Clear cut		Thinning		Clear cut		Clear cut		Thinning	
		P	F	P	F	P	F	P	F	P	F	P	F	P	F	P	F
Baseline_ML	2015	1.3	0.3	0.0	0.0	2.2	0.3	1.0	0.2	0.3	0.2	2.5	0.5	4.9	1.0	2.5	0.5
	2017	1.2	0.3	0.1	0.0	2.5	0.3	1.1	0.3	0.3	0.3	1.8	0.3	4.1	0.9	2.9	0.6
	2020	1.3	0.3	0.1	0.0	2.4	0.3	1.1	0.3	0.5	0.3	1.3	0.3	3.7	0.9	2.8	0.6
	2022	1.3	0.3	0.0	0.0	2.2	0.3	1.0	0.3	0.5	0.3	1.1	0.3	3.5	0.8	2.6	0.6
	2025	1.4	0.3	0.1	0.0	1.9	0.2	0.9	0.3	0.4	0.3	0.8	0.2	3.2	0.8	2.2	0.5
	2030	1.6	0.3	0.0	0.0	1.4	0.2	0.7	0.3	0.4	0.3	0.4	0.2	2.8	0.7	1.8	0.5
	2035	1.9	0.3	0.0	0.0	0.8	0.2	0.6	0.2	0.6	0.3	0.2	0.1	2.6	0.6	1.4	0.4
	2040	2.1	0.4	0.0	0.0	0.0	0.0	0.4	0.2	0.7	0.2	0.1	0.0	2.6	0.6	0.7	0.3

Table 3.22 ***(continued)***

Scenario	Year	Conventional wood (logging residues) (million acres)						Whole-tree biomass (million acres)						Total (million acres)			
		Class 1 stand		Class 2 stand				Class 2 stand				Class 3 stand					
		Clear cut		Clear cut		Thinning		Clear cut		Thinning		Clear cut		Clear cut		Thinning	
		P	F	P	F	P	F	P	F	P	F	P	F	P	F	P	F
MM	2015	1.2	0.2	0.3	0.0	2.3	0.3	0.7	0.2	0.2	0.2	2.5	0.5	4.7	1.0	2.5	0.5
	2017	1.2	0.3	0.1	0.0	2.5	0.3	1.0	0.3	0.4	0.3	1.7	0.3	4.0	0.8	2.9	0.6
	2020	1.3	0.3	0.1	0.0	2.3	0.2	1.0	0.3	0.5	0.3	1.2	0.3	3.5	0.8	2.8	0.6
	2022	1.3	0.3	0.1	0.0	2.1	0.2	0.9	0.3	0.5	0.3	1.0	0.2	3.3	0.7	2.6	0.6
	2025	1.4	0.3	0.1	0.0	1.8	0.2	0.7	0.3	0.4	0.3	0.7	0.2	2.9	0.7	2.1	0.5
	2030	1.6	0.3	0.1	0.0	1.4	0.2	0.6	0.2	0.3	0.3	0.2	0.1	2.5	0.6	1.7	0.5
	2035	1.7	0.3	0.0	0.0	0.9	0.2	0.5	0.2	0.4	0.2	0.1	0.0	2.3	0.5	1.3	0.4
	2040	2.0	0.3	0.0	0.0	0.0	0.0	0.3	0.1	0.5	0.2	0.0	0.0	2.4	0.4	0.6	0.2
MH	2015	1.2	0.2	0.3	0.0	2.3	0.3	0.7	0.2	0.2	0.2	2.5	0.5	4.7	1.0	2.6	0.5
	2017	1.2	0.3	0.1	0.0	2.5	0.2	0.9	0.2	0.4	0.3	1.7	0.3	3.9	0.8	2.8	0.6
	2020	1.3	0.3	0.1	0.0	2.2	0.2	0.9	0.2	0.5	0.3	1.2	0.3	3.4	0.8	2.7	0.6
	2022	1.3	0.3	0.1	0.0	1.9	0.2	0.8	0.2	0.6	0.3	0.9	0.2	3.1	0.7	2.5	0.5
	2025	1.4	0.3	0.1	0.0	1.6	0.2	0.7	0.2	0.5	0.3	0.6	0.1	2.8	0.7	2.1	0.5
	2030	1.5	0.3	0.1	0.0	1.2	0.2	0.6	0.2	0.5	0.2	0.2	0.1	2.4	0.6	1.8	0.4
	2035	1.7	0.3	0.0	0.0	0.9	0.2	0.4	0.2	0.3	0.2	0.1	0.0	2.2	0.4	1.2	0.3
	2040	2.0	0.3	0.0	0.0	0.0	0.0	0.3	0.1	0.5	0.1	0.0	0.0	2.3	0.4	0.5	0.1
HL	2015	1.4	0.3	0.0	0.0	2.1	0.3	1.0	0.2	0.4	0.2	2.5	0.5	4.9	1.0	2.5	0.5
	2017	1.2	0.3	0.1	0.0	2.5	0.3	1.1	0.3	0.3	0.3	1.8	0.3	4.1	0.9	2.9	0.6
	2020	1.3	0.3	0.1	0.0	2.4	0.3	1.1	0.3	0.5	0.3	1.3	0.3	3.7	0.9	2.8	0.6
	2022	1.3	0.3	0.0	0.0	2.2	0.3	1.0	0.3	0.5	0.3	1.1	0.3	3.5	0.8	2.6	0.6
	2025	1.4	0.3	0.1	0.0	1.8	0.2	0.9	0.3	0.4	0.3	0.8	0.2	3.2	0.8	2.2	0.5
	2030	1.7	0.3	0.0	0.0	1.4	0.2	0.7	0.3	0.4	0.3	0.4	0.2	2.8	0.7	1.8	0.5
	2035	1.9	0.3	0.0	0.0	0.8	0.2	0.6	0.2	0.6	0.3	0.2	0.1	2.6	0.6	1.4	0.4
	2040	2.2	0.4	0.0	0.0	0.0	0.0	0.4	0.2	0.7	0.2	0.1	0.0	2.6	0.6	0.7	0.2
HM	2015	1.2	0.2	0.3	0.0	2.3	0.3	0.7	0.2	0.2	0.2	2.5	0.5	4.7	1.0	2.5	0.5
	2017	1.2	0.3	0.1	0.0	2.5	0.3	1.0	0.3	0.4	0.3	1.7	0.3	4.0	0.8	2.9	0.6
	2020	1.3	0.3	0.1	0.0	2.3	0.3	1.0	0.3	0.5	0.3	1.2	0.3	3.6	0.8	2.8	0.6
	2022	1.3	0.3	0.1	0.0	2.1	0.3	0.9	0.3	0.5	0.3	1.0	0.2	3.3	0.7	2.6	0.6
	2025	1.4	0.3	0.1	0.0	1.8	0.2	0.7	0.3	0.4	0.3	0.7	0.2	2.9	0.7	2.1	0.5
	2030	1.6	0.3	0.1	0.0	1.4	0.2	0.6	0.2	0.3	0.3	0.3	0.1	2.5	0.6	1.7	0.5
	2035	1.8	0.3	0.0	0.0	0.9	0.2	0.5	0.2	0.4	0.2	0.1	0.0	2.3	0.5	1.3	0.4
	2040	2.1	0.3	0.0	0.0	0.0	0.0	0.3	0.1	0.5	0.2	0.0	0.0	2.4	0.5	0.5	0.2
HH	2015	1.2	0.2	0.3	0.0	2.3	0.3	0.7	0.2	0.2	0.2	2.5	0.5	4.7	1.0	2.6	0.5
	2017	1.2	0.3	0.1	0.0	2.5	0.2	0.9	0.2	0.4	0.3	1.7	0.3	3.9	0.8	2.8	0.6
	2020	1.3	0.3	0.1	0.0	2.2	0.2	0.9	0.2	0.5	0.3	1.2	0.3	3.5	0.8	2.7	0.6
	2022	1.4	0.3	0.1	0.0	1.9	0.2	0.8	0.2	0.6	0.3	0.9	0.2	3.2	0.7	2.5	0.5
	2025	1.4	0.3	0.1	0.0	1.6	0.2	0.7	0.2	0.5	0.3	0.6	0.1	2.8	0.7	2.1	0.5
	2030	1.6	0.3	0.1	0.0	1.2	0.2	0.6	0.2	0.5	0.2	0.2	0.1	2.4	0.6	1.8	0.4
	2035	1.7	0.3	0.0	0.0	0.9	0.2	0.4	0.2	0.3	0.2	0.1	0.0	2.2	0.4	1.2	0.3
	2040	2.0	0.3	0.0	0.0	0.0	0.0	0.3	0.1	0.5	0.1	0.0	0.0	2.3	0.4	0.5	0.1

Table 3.22 presents the harvested acres by scenario to meet the USFPM projection for conventional wood and biomass feedstocks demand. Annually, the number of acres harvested varies from a maximum of about 5.4 million acres to a low of 2.8 million acres, with variations among both scenario and year. This is about 1% of the total 386 million acres available. Under scenarios Baseline_ML and HL, logging residues alone are sufficient to meet the woody biomass demand for biomass feedstock; therefore, class 2 and class 3 stands for biomass feedstocks are not harvested as biomass feedstocks. Whole trees in class 2 and class 3 stands are harvested to meet the woody biomass demand under scenarios MM, MH, HM, and HH. Among them, most of the acres harvested are from class 3 stands. Overall, a significant portion of the harvest is from thinning class 2 timberland stands. Overall, thinning accounts for 33%–52% of the acres harvested. This occurs because the fixed ratio of clear-cut to thinning acres is pre-specified in the model. Finally, most of the acres are private land—more than 80% or 90% in every scenario and every year.

Following the USFPM projected demand pathways (fig. 3.19), the model can also be used to simulate supply curves for a particular year of interest for each scenario. Section 3.4.2 provides an explanation of the methodology. For example, in the HH scenario, the supply target for 2014 is 17 million dry tons, for 2015–2019 is 22 million dry tons, and for 2020 is 29 million dry tons. To simulate the supply curve for 2025, the model will solve from 2014 to 2024 first to meet each year's demand, then simulate supply targets from low to high with a 1 million dry ton increment to obtain shadow prices at the different supply targets, up to 184 million dry tons for 2025. The same is true for the supply curve for 2040: the model will solve for the projected supply for previous years before starting to simulate the supply curve for 2040. Figure 3.20 presents the derived supply curve for the Baseline_ML and HH scenarios for 2015, 2020, 2025, 2030, 2035, and 2040.

Figure 3.19 | USFPM projected biomass feedstock demand pathways for the Baseline_ML (top) and HH (bottom) scenarios along with the corresponding shadow prices

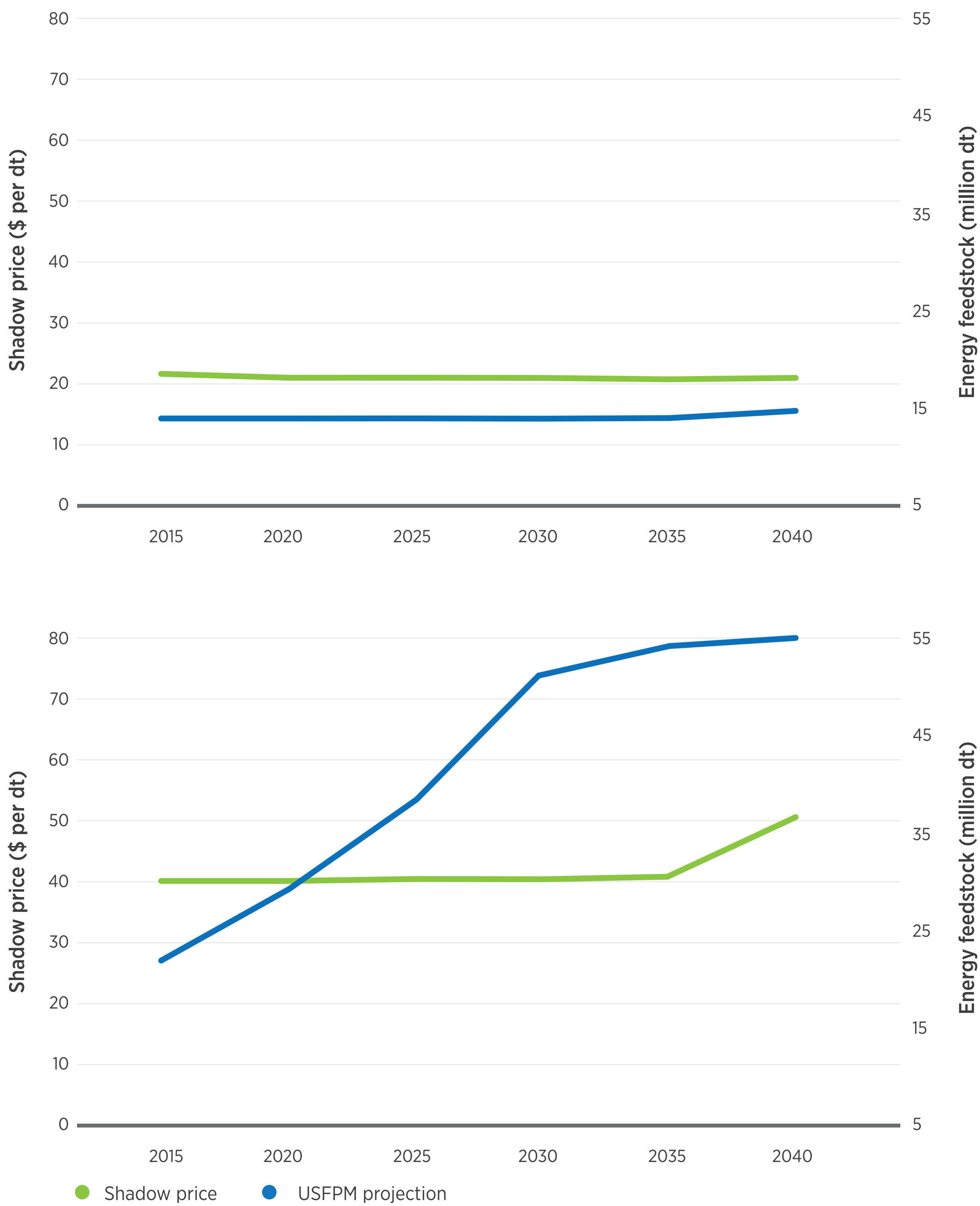
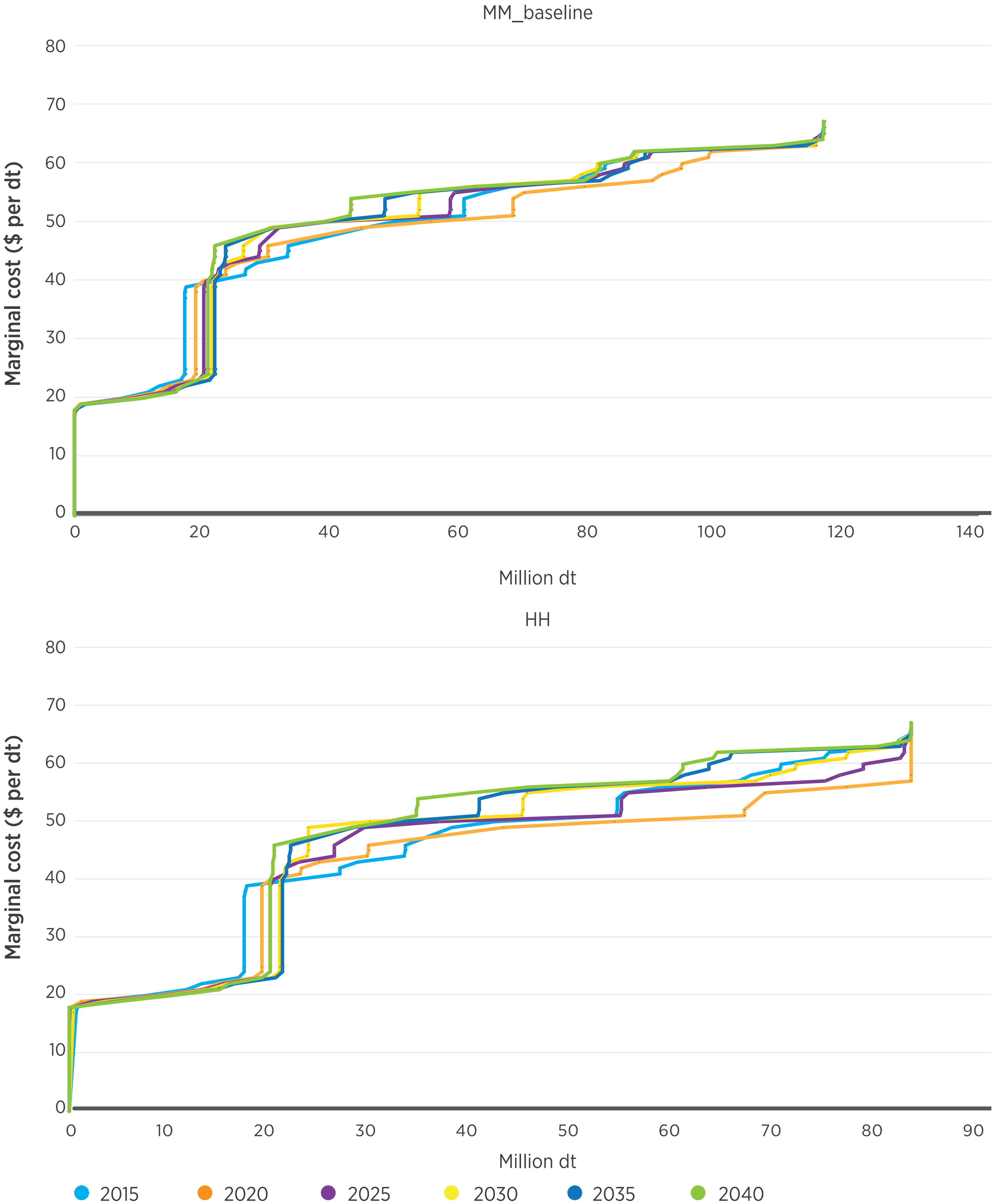


Figure 3.20 | Supply curves for the Baseline_ML and HH scenarios for 2015, 2020, 2025, 2030, 2035, and 2040



Note: Marginal costs are the production costs derived from stumpage prices and harvest costs.

Table 3.23 | Acres Harvested by Scenario, Ownership, Year, and Cost per Dry Ton (P = private; F = federal)

Year	Marginal cost ($/dry ton)	Scenario (million acres)																	
		Baseline_ML			MM			MH			HL			HM			HH		
		P	F	Total	P	F	Total	P	F	Total	P	F	Total	P	F	Total	P	F	Total
2015	40	4.5	0.7	5.2	4.7	0.7	5.4	4.7	0.7	5.4	4.4	0.7	5.1	4.7	0.7	5.4	4.7	0.7	5.4
2015	60	7.4	1.5	8.9	7.2	1.4	8.7	7.2	1.4	8.7	7.4	1.5	8.9	7.3	1.4	8.7	7.2	1.4	8.7
2015	80	8.6	1.7	10.3	8.1	1.6	9.7	7.7	1.6	9.2	8.6	1.7	10.4	8.1	1.6	9.7	7.7	1.6	9.3
2017	40	4.3	0.6	4.9	4.2	0.6	4.8	4.2	0.6	4.8	4.3	0.6	4.9	4.2	0.6	4.8	4.2	0.6	4.8
2017	60	7.0	1.5	8.5	6.9	1.4	8.3	6.7	1.4	8.1	7.0	1.5	8.5	6.9	1.4	8.3	6.7	1.4	8.1
2017	80	8.0	1.7	9.7	7.2	1.6	8.7	6.8	1.4	8.3	8.0	1.7	9.7	7.2	1.6	8.8	6.9	1.4	8.3
2020	40	3.9	0.6	4.4	3.7	0.5	4.3	3.7	0.5	4.2	3.9	0.6	4.4	3.8	0.5	4.3	3.7	0.5	4.2
2020	60	6.6	1.4	8.0	6.3	1.4	7.7	6.1	1.3	7.4	6.6	1.4	8.0	6.3	1.4	7.7	6.2	1.3	7.5
2020	80	7.3	1.6	8.9	6.5	1.5	8.0	6.1	1.3	7.4	7.3	1.6	8.9	6.5	1.5	8.0	6.2	1.3	7.5
2022	40	3.7	0.6	4.2	3.5	0.5	4.1	3.4	0.5	3.9	3.7	0.6	4.2	3.6	0.5	4.1	3.5	0.5	4.0
2022	60	6.2	1.4	7.6	5.8	1.3	7.2	5.6	1.2	6.9	6.2	1.4	7.6	5.9	1.3	7.2	5.7	1.2	6.9
2022	80	6.9	1.5	8.4	6.0	1.4	7.4	5.6	1.2	6.9	6.9	1.6	8.5	6.1	1.4	7.5	5.7	1.2	6.9
2025	40	3.4	0.5	3.9	3.3	0.5	3.8	3.1	0.5	3.6	3.4	0.5	4.0	3.3	0.5	3.8	3.2	0.5	3.7
2025	60	5.4	1.3	6.7	5.0	1.2	6.2	4.9	1.2	6.0	5.4	1.3	6.7	5.0	1.2	6.2	4.9	1.2	6.1
2025	80	6.3	1.5	7.8	5.4	1.3	6.8	5.0	1.2	6.3	6.3	1.5	7.8	5.5	1.3	6.8	5.1	1.2	6.3
2030	40	3.1	0.5	3.6	3.0	0.5	3.5	2.9	0.5	3.3	3.1	0.5	3.6	3.1	0.5	3.5	2.9	0.5	3.4
2030	60	4.6	1.2	5.8	4.2	1.1	5.3	4.1	1.0	5.1	4.6	1.2	5.8	4.2	1.1	5.3	4.2	1.0	5.2
2030	80	5.6	1.4	6.9	4.8	1.2	6.0	4.4	1.1	5.5	5.6	1.4	7.0	4.9	1.2	6.1	4.5	1.1	5.6
2035	40	2.7	0.5	3.2	2.7	0.4	3.1	2.6	0.4	3.0	2.7	0.5	3.2	2.7	0.4	3.1	2.6	0.4	3.0
2035	60	4.0	1.1	5.1	3.6	0.9	4.5	3.4	0.8	4.2	4.1	1.1	5.1	3.6	0.9	4.5	3.4	0.8	4.2
2035	80	4.7	1.3	5.9	4.1	1.0	5.1	3.8	0.9	4.7	4.7	1.3	6.0	4.1	1.0	5.2	3.8	0.9	4.8
2040	40	2.2	0.4	2.5	2.1	0.3	2.4	2.0	0.3	2.3	2.2	0.4	2.6	2.1	0.3	2.4	2.0	0.3	2.3
2040	60	3.3	0.9	4.2	2.9	0.6	3.5	2.8	0.5	3.3	3.3	0.8	4.2	2.9	0.6	3.6	2.8	0.5	3.4
2040	80	4.0	1.1	5.1	3.5	0.8	4.3	3.2	0.7	3.9	4.1	1.1	5.2	3.5	0.8	4.3	3.3	0.7	4.0

Table 3.23 shows the acres harvested for three selected costs from the developed supply curves. The associated tonnages are shown in table 3.24. Since these acres and tons are derived from the supply curves, the result is the amount of biomass available at a given price by year and scenario. The variables are also broken out by ownership—federal and private. As would be expected, the amount of available biomass and the associated acres increase with price (i.e., more biomass is available at a higher price on the market). As an example, for 2015 baseline and HH scenarios, the amount of biomass increases about eightfold, going from $40 per dry ton to $80 per dry ton. Similar supply curves produce the approximate same increases for the other scenarios. Available biomass ranges from about 20 million dry tons annually to about 185 million dry tons annually depending on the scenario, year, and selected cost. There is a general trend to increase the amount of available biomass over time because of the growing, dynamic forests.

However, there are noticeable decreases of available biomass in the 2040 time period compared with earlier years. The reason is that additional biomass is not grown on plantations, as reported in the RPA (U.S. Forest Service 2012). In higher biomass demand scenarios, in this model as well, additional plantations are established to provide the supply. However, in the ForSEAM model, natural forests are not reestablished as plantations for biomass. No additional plantations are established to meet the high demand scenario biomass requirements. (This issue is discussed in more detail in section 3.1.)

Density maps (fig. 3.21) illustrate where whole trees (by stand species: softwood, hardwood, mixed wood) could be harvested based on the model solution if the woody biomass supply target were 40 million dry tons in 2020. Most softwood is harvested in the southern regions, and most hardwood in the northeastern and southern regions.

Table 3.24 | Dry Tons of Biomass by Feedstock Type, Stand Diameter Class, Cut Option, Ownership, Scenario, and Year at $60 per Dry Ton (P = private; F = federal)

Scenario	Year	Conventional wood (logging residues) (million acres)						Whole-tree biomass (million acres)						Total (million acres)			
		Class 1 stand		Class 2 stand				Class 2 stand				Class 3 stand					
		Clear cut		Clear cut		Thinning		Clear cut		Thinning		Clear cut		Clear cut		Thinning	
		P	F	P	F	P	F	P	F	P	F	P	F	P	F	P	F
Baseline_ML	2015	8.7	1.3	0.1	0.0	6.3	0.8	32.0	7.4	6.0	3.8	13.5	2.5	54.3	11.2	12.2	4.6
	2017	8.0	1.3	0.2	0.0	7.5	0.9	35.7	9.6	5.8	5.9	10.8	2.0	54.8	13.0	13.3	6.8
	2020	8.7	1.4	0.2	0.0	7.7	0.9	38.3	9.9	9.4	6.5	9.3	1.9	56.5	13.1	17.1	7.4
	2022	9.3	1.4	0.2	0.0	7.6	0.9	37.2	9.9	9.8	6.6	8.4	1.8	55.1	13.1	17.4	7.5
	2025	10.4	1.5	0.2	0.0	7.2	0.9	32.3	9.7	7.9	6.5	6.9	1.7	49.8	12.9	15.1	7.5
	2030	12.6	1.6	0.1	0.0	6.1	0.9	29.6	9.2	9.6	6.4	3.5	1.4	45.8	12.3	15.8	7.3
	2035	15.1	1.8	0.1	0.0	4.0	0.8	26.1	9.2	19.7	7.3	1.3	0.4	42.6	11.4	23.8	8.1
	2040	18.3	2.4	0.0	0.0	0.1	0.0	19.8	7.6	25.5	6.7	0.8	0.3	38.9	10.2	25.6	6.8
MM	2015	7.7	1.3	0.9	0.0	6.5	0.9	23.6	7.0	3.9	3.4	13.5	2.5	45.7	10.8	10.4	4.3
	2017	8.1	1.3	0.3	0.0	7.4	0.9	32.5	9.3	6.3	5.9	10.5	1.9	51.4	12.5	13.7	6.8
	2020	8.8	1.4	0.3	0.1	7.5	0.8	33.6	8.8	9.8	6.5	8.9	1.8	51.7	12.0	17.3	7.4
	2022	9.4	1.4	0.2	0.0	7.4	0.9	32.9	9.3	10.3	6.5	7.7	1.6	50.3	12.4	17.6	7.4
	2025	10.5	1.5	0.2	0.0	6.8	0.9	28.1	9.4	8.0	6.4	5.8	1.4	44.6	12.3	14.9	7.4
	2030	12.2	1.6	0.4	0.0	6.1	0.9	23.6	8.5	7.7	6.1	2.3	1.0	38.5	11.1	13.7	7.0
	2035	14.1	1.7	0.1	0.0	4.7	0.8	22.7	7.8	10.8	5.7	0.6	0.2	37.5	9.7	15.5	6.5
	2040	17.7	2.3	0.0	0.0	0.1	0.0	15.7	5.2	19.8	4.5	0.3	0.1	33.7	7.6	19.9	4.5

Table 3.24 ***(continued)***

Scenario	Year	Conventional wood (logging residues) (million acres)						Whole-tree biomass (million acres)						Total (million acres)			
		Class 1 stand		Class 2 stand				Class 2 stand				Class 3 stand					
		Clear cut		Clear cut		Thinning		Clear cut		Thinning		Clear cut		Clear cut		Thinning	
		P	F	P	F	P	F	P	F	P	F	P	F	P	F	P	F
MH	2015	7.8	1.3	0.9	0.0	6.5	0.9	22.5	6.9	4.0	3.5	13.5	2.5	44.6	10.6	10.5	4.3
	2017	8.2	1.3	0.4	0.1	7.2	0.8	29.4	7.4	6.2	5.9	10.4	1.9	48.4	10.7	13.3	6.7
	2020	8.9	1.4	0.4	0.1	7.1	0.8	29.4	7.3	9.8	6.2	8.7	1.8	47.5	10.6	16.9	7.0
	2022	9.5	1.4	0.5	0.1	6.8	0.8	28.2	7.3	12.3	6.4	7.2	1.5	45.4	10.4	19.0	7.2
	2025	10.6	1.5	0.4	0.1	6.2	0.8	24.9	8.0	12.1	6.7	5.1	1.2	41.0	10.8	18.3	7.6
	2030	12.0	1.6	0.4	0.0	5.4	0.9	21.9	7.4	13.7	5.4	2.0	0.8	36.3	9.8	19.1	6.3
	2035	13.5	1.7	0.1	0.0	4.6	0.9	20.8	6.4	9.5	4.2	0.6	0.2	35.0	8.3	14.1	5.0
	2040	17.3	2.3	0.0	0.0	0.0	0.0	14.2	3.9	18.6	3.3	0.2	0.1	31.7	6.3	18.7	3.3
HL	2015	8.8	1.3	0.1	0.0	6.2	0.8	32.0	7.4	6.9	3.9	13.5	2.5	54.4	11.2	13.0	4.7
	2017	8.1	1.3	0.2	0.0	7.5	0.9	35.8	9.7	5.8	5.9	10.8	2.0	54.9	13.0	13.3	6.8
	2020	8.8	1.4	0.2	0.0	7.7	0.9	38.4	9.9	9.4	6.5	9.3	1.9	56.6	13.2	17.1	7.4
	2022	9.4	1.4	0.2	0.0	7.6	0.9	37.3	9.9	9.8	6.6	8.4	1.8	55.3	13.2	17.4	7.5
	2025	10.5	1.5	0.2	0.0	7.2	0.9	32.4	9.8	7.9	6.5	6.9	1.7	50.0	12.9	15.1	7.5
	2030	12.9	1.6	0.0	0.0	6.1	0.9	29.9	9.2	9.9	6.4	3.5	1.4	46.3	12.3	16.0	7.3
	2035	15.4	1.8	0.1	0.0	3.9	0.7	26.1	9.2	20.2	7.3	1.3	0.4	42.9	11.4	24.1	8.1
	2040	18.6	2.4	0.0	0.0	0.0	0.0	19.9	7.6	25.6	6.7	0.8	0.3	39.3	10.3	25.6	6.7
HM	2015	7.7	1.3	0.9	0.0	6.5	0.9	23.8	7.0	3.9	3.4	13.5	2.5	46.0	10.8	10.4	4.3
	2017	8.1	1.3	0.3	0.0	7.4	0.9	32.7	9.3	6.2	5.9	10.5	1.9	51.5	12.5	13.6	6.8
	2020	8.9	1.4	0.3	0.0	7.5	0.9	34.0	9.3	9.5	6.4	8.9	1.8	52.1	12.5	17.0	7.3
	2022	9.5	1.4	0.2	0.0	7.4	0.9	33.3	9.6	9.9	6.5	7.7	1.6	50.7	12.6	17.3	7.4
	2025	10.6	1.5	0.3	0.0	6.9	0.9	27.9	9.4	7.8	6.4	5.8	1.4	44.6	12.3	14.6	7.3
	2030	12.4	1.6	0.4	0.0	6.0	0.9	23.6	8.5	7.5	6.0	2.3	1.0	38.6	11.1	13.5	7.0
	2035	14.4	1.7	0.1	0.0	4.6	0.8	22.7	7.9	11.1	5.8	0.6	0.2	37.8	9.8	15.7	6.6
	2040	18.0	2.3	0.0	0.0	0.1	0.0	15.7	5.3	19.8	4.6	0.3	0.1	33.9	7.7	19.8	4.6
HH	2015	7.8	1.3	0.9	0.0	6.5	0.9	22.7	6.9	4.0	3.5	13.5	2.5	44.8	10.7	10.5	4.3
	2017	8.2	1.3	0.4	0.1	7.1	0.8	29.6	7.4	6.1	5.9	10.4	1.9	48.6	10.8	13.3	6.6
	2020	9.0	1.4	0.4	0.1	7.2	0.8	29.8	7.3	10.2	6.2	8.7	1.8	47.9	10.7	17.4	7.0
	2022	9.6	1.4	0.5	0.1	6.8	0.8	28.5	7.4	12.6	6.4	7.2	1.5	45.9	10.5	19.4	7.3
	2025	10.7	1.5	0.3	0.1	6.3	0.8	25.7	8.2	11.5	6.8	5.1	1.2	41.9	11.0	17.8	7.6
	2030	12.3	1.6	0.4	0.0	5.5	0.9	22.0	7.5	13.3	5.5	2.0	0.8	36.6	9.9	18.8	6.4
	2035	13.8	1.7	0.1	0.0	4.6	0.8	20.8	6.5	9.8	4.3	0.6	0.2	35.3	8.4	14.4	5.1
	2040	17.5	2.3	0.0	0.0	0.0	0.0	14.3	4.0	18.7	3.4	0.2	0.1	32.0	6.4	18.7	3.4

Table 3.24 is the companion table to table 3.22. Table 3.25 presents the biomass tons associated with the harvested acres in table 3.23. Tons are shown by selected years and cost for all scenarios. As expected, biomass availability increases with the higher marginal costs as represented graphically in figures 3.19 and 3.20. However, biomass availability does not always increase with years. As explained previously and shown in this tabular data summary, biomass tonnages do not necessarily increase with the higher biomass demand scenarios, MH and HH. This is a result of the restriction of the model not to replace natural stands with plantations for biomass. For the baseline (ML) scenario, there are about 20–115 million dry tons of biomass potential depending on selected cost and year. For the same factors in the HH scenario, the potential biomass is about 20–80 million dry tons.

Figure 3.21 | Density maps for whole trees harvested for 40 million dry tons of woody biomass in the baseline scenario, 2020, for (A) hardwood, (B) softwood, and (C) mixed, and for hardwood, softwood, and mixed for 80 million dry tons (D, E, F), and 120 million dry tons (G, H, I)

Figure 3.21 *(continued)* | 80 million dry tons, (D) hardwood, (E) softwood, and (F) mixed

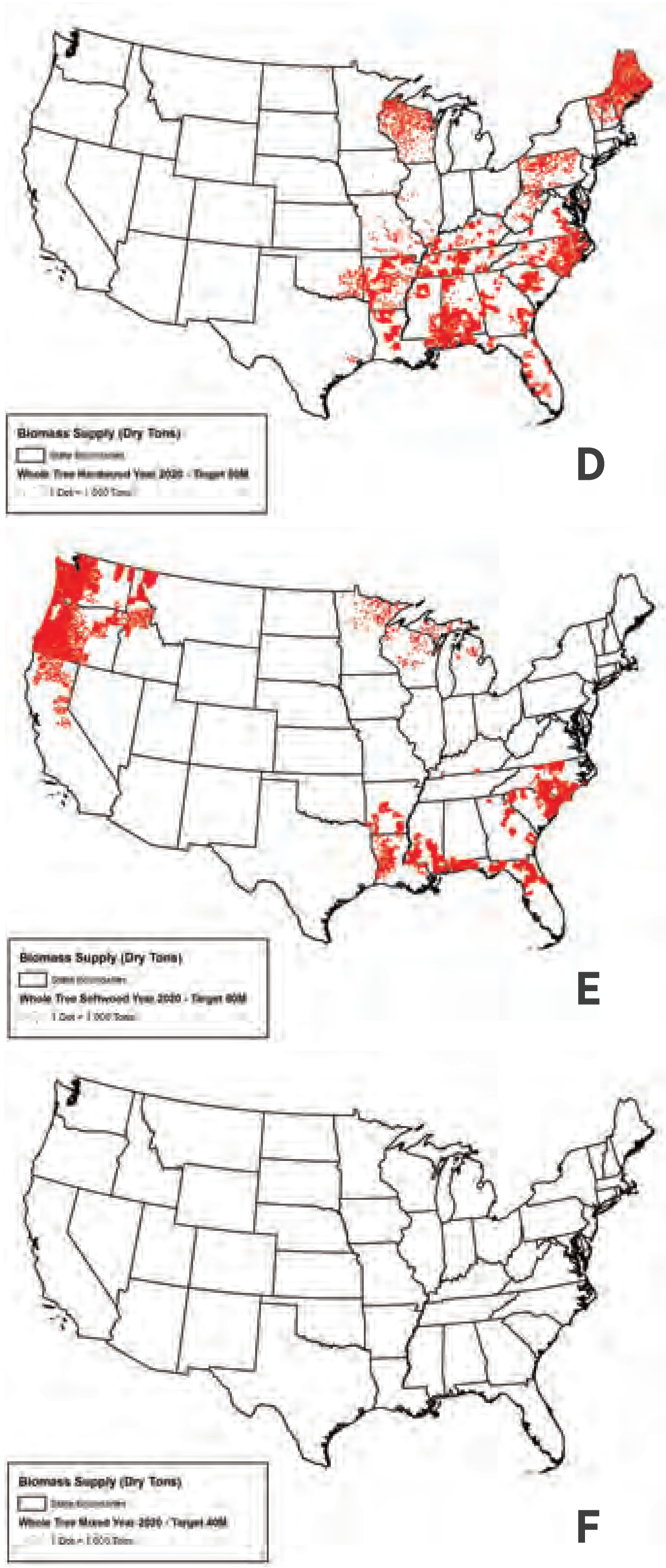


Figure 3.21 *(continued)* | 120 million dry tons, (G) hardwood, (H) softwood, and (I) mixed

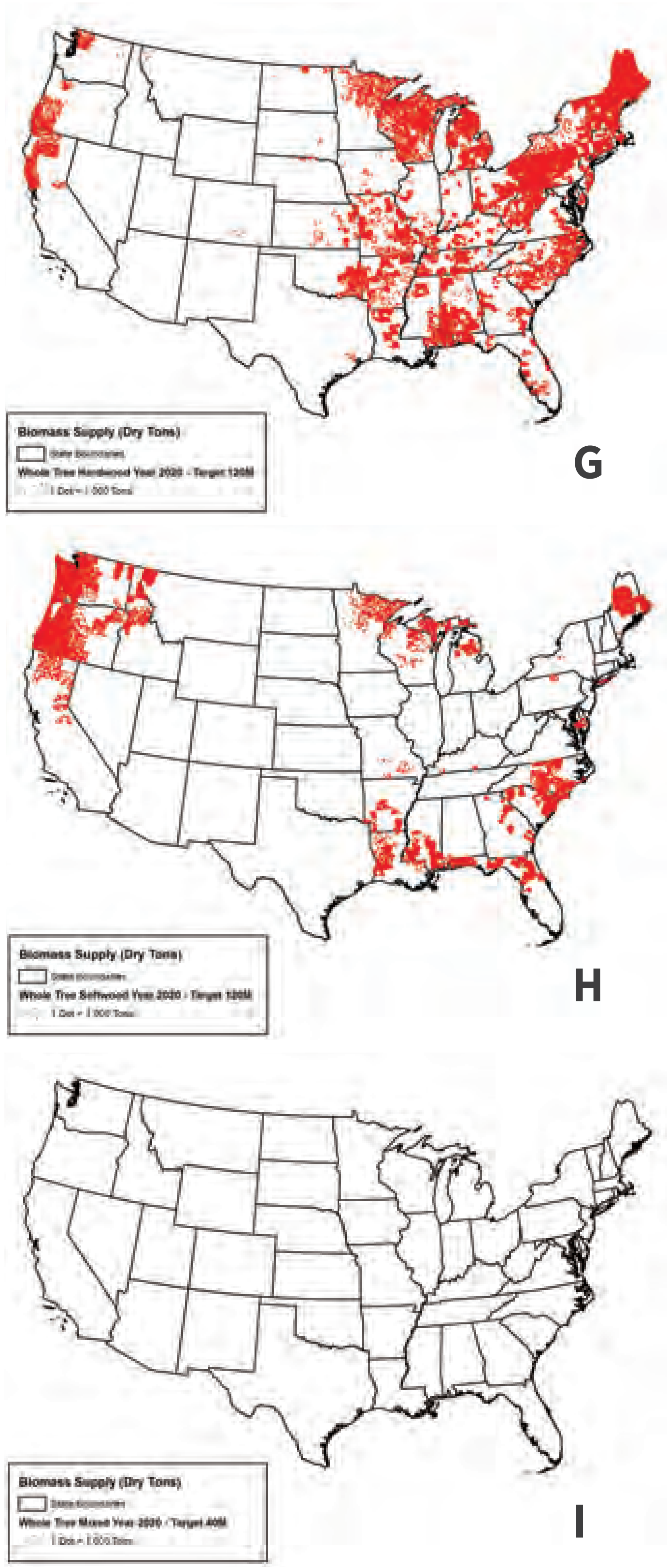


Table 3.25 | Dry Tons of Biomass Supplied by Price per Ton and Scenario, 2015–2040

Year	Marginal cost ($/dry ton)	Scenario (million dry tons)					
		ML	HL	MM	MH	HM	HH
2015	40	22.0	22.0	22.1	22.1	22.1	22.1
2015	60	82.3	83.3	71.1	70.0	71.4	70.2
2015	80	116.0	117.0	93.0	82.0	94.0	83.0
2017	40	21.0	21.1	20.6	20.6	20.7	20.6
2017	60	87.8	88.0	84.4	79.1	84.4	79.3
2017	80	116.0	117.0	93.0	82.0	94.0	83.0
2020	40	20.1	20.2	19.8	19.7	19.9	19.9
2020	60	94.1	94.3	88.4	82.0	89.0	83.0
2020	80	116.0	117.0	93.0	82.0	94.0	83.0
2022	40	20.5	20.6	20.1	19.8	20.2	20.0
2022	60	93.1	93.4	87.7	82.0	88.0	83.0
2022	80	116.0	117.0	93.0	82.0	94.0	83.0
2025	40	20.6	20.7	20.3	19.9	20.5	20.1
2025	60	85.2	85.4	79.1	77.7	78.8	78.3
2025	80	116.0	117.0	93.0	82.0	94.0	83.0
2030	40	21.7	21.8	21.2	20.6	21.5	20.8
2030	60	81.1	81.9	70.3	71.5	70.2	71.7
2030	80	116.0	117.0	93.0	82.0	94.0	83.0
2035	40	21.8	22.0	21.4	20.8	21.6	21.0
2035	60	85.8	86.5	69.3	62.4	69.9	63.2
2035	80	116.0	117.0	93.0	82.0	94.0	83.0
2040	40	20.8	21.1	20.2	19.6	20.4	19.9
2040	60	81.5	81.9	65.7	60.0	66.1	60.6
2040	80	116.0	117.0	93.0	82.0	94.0	83.0

3.4.5 Conclusions

ForSEAM is a dynamic linear optimization model that solves for a least-cost mix of both conventional wood and biomass feedstock from private timberland, subject to timberland area, harvest intensity, and forest management (e.g., thinning, cut-to-length, replanting). Because of regional differences in forest management and data limitations in certain regions, assumptions are made and parameters estimated to reflect reality. The dynamic feature of the model allows users to examine future supplies of wood products based on past activities.

Given USFPM projections of conventional wood and biomass feedstock supply targets, ForSEAM can derive the shadow price for each year as annual demand changes over time. The future shadow price tends to spike if the previous-year demand is high, leaving less available timber for biomass feedstocks. If annual demands are the same from 2014 to 2040, the HH supply curve tends to shift to the left because increasing demand for conventional wood can make less expensive logging residues available to meet the biomass feedstock demand.

There are, however, limitations to applying this model to estimate available biomass feedstocks. The years 2014 to 2040—a span of only 27 years—is considered a short time period for some timber types, especially for stands in the West. Since data are limited regarding stand age and quadratic mean diameters, they are assumed to be constant for each stand diameter class group and tree type. Improvements could be made if, in the future, age and quadratic mean diameter distributions could be determined. This would likely increase the precision of estimates; but it might not affect the results for estimating woody biomass supply because it takes at least 7 years, and sometimes as long as 27 years, for a class 3 stand to become a class 2 stand or for replanted acres to grow to a pulpwood or class 2 stand. The current estimates of biomass feedstocks potentially harvested are probably a conservative estimate.

Many of the assumptions can be changed and adjusted with improved regional parameters or other information. Currently, assumptions regarding harvest intensity, growth, and replanting provide a more conservative estimate; yet the results are robust, and harvest activity intensities reflect the current location of abundant timber resources. Only a very small percentage of the available timberland is used to meet the supply target annually. The model shows the potential for increasing biomass feedstocks supply from forests in the next 20 years or so.

3.5 Wood Energy Demand in the Context of Southern Forest Resource Markets

3.5.1 Introduction

Conditions in the forests of the South[7] and the existence of active forest products markets have contributed to the development of a new wood-pellet-for-export industry, which has the potential to dwarf all current domestic uses of southern wood for energy in the near term (Abt et al. 2014). About 46% of the South is forested, compared with only 34% of the United States as a whole (Oswalt et al. 2014). The South includes more than 40% of all U.S. timberland[8] and contains more than 72% of all planted U.S. timberland (Oswalt et al. 2014). The region is easily

[7] Throughout section 3.5, the South is defined as including all of the 13 states of Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, Oklahoma, South Carolina, Tennessee, Texas, and Virginia.

[8] "Forestland" is defined on p. 31 of appendix A of Oswalt et al. (2014). Timberland is a subset of forestland that can produce timber volume at a rate of 20 cubic feet/acre/year and is not legally or administratively restricted from timber harvest.

accessible for transport of wood to both domestic (rail and roads) and international (ports) destinations. The timberland in the South has provided about 63% of all U.S. timber harvested since 1996, nearly all of it from private land (Oswalt et al. 2014). The existing demands on the forests for wood for lumber, paper, composites, and other uses, in addition to these new energy demands, interact with the existing forest conditions and lead to changes in both timber markets and future forest conditions.

In this section, we discuss the factors influencing demand for wood (USDA Forest Service 2015a) and the factors influencing the supply of wood (USDA Forest Service 2015b) for both energy and conventional products in the South. We then use a partial equilibrium timber market model to evaluate a set of combinations of these factors to illustrate the impacts of the supply and demand factors on market outcomes. Using subregions of the U.S. Coastal South, we evaluate (1) competing pulpwood demands, (2) declines in sawtimber harvest (i.e., the "sawtimber overhang"), (3) substitution of mill residues for small roundwood, and (4) changes in timberland area. The simulations of market impacts on the prices, inventory, and removals of timber, and timberland area by management type are discussed.

3.5.2 Demand Factors

Historically, wood energy use in the United States has primarily consisted of (1) residential wood use for heat and (2) coproduction of heat and energy in the wood products industry (Ince et al. 2011a). More recently, domestic and international renewable energy policies are key drivers of the demands for wood for use for energy and, in particular, of the demands for bulk industrial pellets for export. Other demand factors—including those influencing conventional wood products—that have impacts on the markets for wood biomass feedstocks are illustrated using timber use data from recent surveys (USDA Forest Service 2015b). This section also discusses projections of new wood energy facilities in the South as developed by Forisk Consulting (2015).

3.5.3 International Policies

The 2009 European Union (EU) Renewable Energy Directive[9] and related guidance are likely the most significant international policies affecting U.S. pellet manufacturing and thus U.S. forests. These policies require (1) a 20% EU-wide renewable energy component, with each member state generating a set share of renewable energy; (2) a 20% reduction in GHG emissions[10] and in member state annual emission allocations for the period from 2013 to 2020;[11] and (3) a 20% improvement in efficiency.[12] Combined, these policy initiatives seek to promote renewable, low-GHG, efficient sources of energy.

[9] Directive 2009/28/EC of the European Parliament and of the Council of April 23, 2009, on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC (known as the Renewable Energy Directive). OJ L 140/16, http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32009L0028&from=EN.

[10] Decision 406/2009/EC of the European Parliament and of the Council of April 23, 2009, on the efforts of member states to reduce their GHG emissions to meet the Community's GHG emission reduction commitments by up to 2020. OJ L 140/136, http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:140:0136:0148:EN:PDF.

[11] Decision 2013/162/EU. Commission decision of March 26, 2013, on determining member states' annual emission allocations for the period from 2013 to 2020 pursuant to Decision No 406/2009/EC of the European Parliament and of the Council. OJ L 90/106, http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2013:090:0106:0110:EN:PDF.

[12] Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC. OJ L 315/1. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2012:315:0001:0056:EN:PDF.

EU renewable energy policy continues to evolve. On January 22, 2014, the EU announced its 2030 energy framework and objectives, which include a requirement for 40% GHG reduction, a minimum renewable contribution of 27% at the EU level (but not translated to member state targets), and a target energy efficiency improvement of 25% (European Commission 2014a, 2014b). The effect of the new objectives on pellet markets is unclear and will likely remain so until the European Commission, Parliament, and/or Council provides further clarification. A recent EU Commission staff working document (European Commission 2014c) evaluated the current conditions with respect to the solid biomass guidelines and sustainability and concluded that the current array of member state policies did not pose a distortion risk to EU markets. The paper also reiterates the EU Commission position that solid biomass sustainability will continue to be monitored through 2020.

Three critical unknowns that could influence the use of southern timber for wood pellet production are (1) the GHG emissions reduction from the use of southern timber, (2) the ability of southern forests to meet other sustainability criteria set by the EU or member states, and (3) the availability of governmental subsidies for wood pellet use for energy in the EU.

Stephenson and MacKay (2014) evaluated GHG emissions, biogenic carbon, and indirect land use, using a life-cycle analysis tool and counterfactual scenarios to identify the most efficient pathways for biomass energy development in the United Kingdom (UK). Current EU GHG emissions accounting rules do not consider either indirect land use changes or changes in biogenic carbon stocks that could result from an increase in harvest to produce feedstocks for pellets to produce renewable energy. Stephenson and MacKay (2014) found that southern timber resources can meet UK GHG emissions reduction criteria in some cases (harvest of pine plantations or use of sawmill residues) but not in others (use of older hardwood stands where rotation ages are assumed to decline).

A second area of uncertainty in pellet market developments is the need to demonstrate compliance with land use restrictions and chain-of-custody provisions of the sustainability criteria. For many EU countries, including the UK, the sustainability requirements can be met through certification of the forest by independent third-party schemes, including the Forest Stewardship Council and the Pan-European Forest Certification. Several overviews of these schemes, including benchmarking them against UK regulations, have concluded that they may require additional inputs to meet the land and chain-of-custody requirements of the EU guidelines and member state regulations; see Kittler et al. (2012) and UK DECC (2014). In addition to the two approved certification schemes (Forest Stewardship Council and Pan-European Forest Certification), legality and sustainability can be demonstrated using specific evidence to meet each of the UK sustainability criteria (UK DECC 2014).

A third area of uncertainty results from the effects of governmental subsidies on the use of wood pellets alone or with co-firing for electricity production. These subsidies are a market intervention that could be interpreted to be either a cause or a result of market imperfections. For example, the policy and subsidy could be assumed to correct the imperfection that results from the free emission and sequestration of carbon, or the policy and subsidy could be assumed to cause a market imperfection by subsidizing one sector at the expense of another. Additional discussion of the scale of the subsidies can be found in Abt et al. (2014).

Subsidies for the use of wood biomass feedstocks are currently provided by governments in the UK and the Netherlands, although recently the UK government proposed some changes in policies that could affect the additional conversion of electricity facilities in the UK to use wood pellets as a feedstock.

3.5.4 Domestic Policies

No current policies specifically encourage or discourage the use of wood pellets in the United States, although there are many existing and potential future policies that could influence both the production and consumption of pellets or other wood for energy production. Historically, the U.S. pellet market has produced bagged pellets for use in residential wood pellet stoves, but the large-scale production of bulk pellets for export is a relatively new phenomenon. Both federal and state policies will influence the future of wood energy production and consumption in the United States.

EISA is the primary U.S. federal law that could indirectly influence pellet production, and thus U.S. forests.[13] EISA requires that any woody biomass used to meet the renewable fuels standard come only from non-federal and non–ecologically sensitive lands and from (a) roundwood and mill residue from existing plantations, (b) slash and pre-commercial thinnings, or (c) wildfire hazard reduction materials. EISA will affect pellet production if (1) cellulosic biofuels become a commercially viable product and begin to affect timber harvests and/or (2) international policies or subsequent domestic policies use the EISA feedstock limits as a basis for their own sustainability criteria. These outcomes would affect forests because limiting the type and location of inventory available for pellet production could change the procurement costs for some wood feedstocks.

Perhaps the most notable policies are taking the form of regulations promulgated by EPA. These policies include the following:

- Proposed new source performance standards[14]
- Proposed guidelines for regulating carbon emissions from fossil fuel power plants under section 111(d) of the Clean Air Act[15]
- The adopted Boiler Maximum Achievable Control Technology rule[16] under the Clean Air Act of 1970
- Non-Hazardous Secondary Material regulations[18] under the Resource Conservation and Recovery Act of 1976[19] (Probert 2012; Tarr and Adair 2014; EIA 2013).

The new source performance standards, as well as guidelines for regulating existing sources under section 111(d) of the Clean Air Act, have the potential to increase the demand for wood energy in the United States. The degree to which they influence domestic demand for wood energy production depends, in part, on rules governing biogenic carbon accounting processes, which are still under development by EPA. If these accounting processes show biomass to be GHG-beneficial relative to other fuels, there

[13] Energy Independence and Security Act of 2007, Pub. L. 110–140, 121 Stat. 1492, https://www.gpo.gov/fdsys/pkg/BILLS-110hr6enr.

[14] EPA National Emission Standards for Hazardous Air Pollutants: Off-Site Waste and Recovery Operations, Final Rule, 78 Fed. Reg.14248, 40 CFR pt. 63, http://www.regulations.gov/#!documentDetail;D=EPA-HQ-OAR-2012-0360-0077.

[15] EPA Carbon Pollution Emission Guidelines for Existing Stationary Sources: Electric Utility Generating Units—Proposed Rule, 79 Fed. Reg. 34830 (proposed June 18, 2014) (to be codified at 40 CFR pt. 60), http://www.regulations.gov/#!documentDetail;D=EPA-HQ-OAR-2013-0602-0001.

[16] EPA National Emissions Standards for Hazardous Air Pollutants for Area Sources: Industrial, Commercial, and Institutional Boilers, Final Rule, 78 Fed Reg. 7487, 40 CFR Part 63, https://federalregister.gov/a/2012-31645.

[17] Clean Air Act of 1970, Pub. L. 159 (July 14, 1955) 69 Stat. 322, and the amendments made by subsequent enactments, 42 U.S.C. 7401–7626, http://www.epw.senate.gov/envlaws/cleanair.pdf.

[18] EPA Commercial and Industrial Solid Waste Incineration Units: Non-Hazardous Secondary Materials That Are Solid Waste, Final Rule, 78 Fed. Reg. 9112 (February 7, 2013) 40 CFR Parts 60 and 241, http://www.regulations.gov/#!documentDetail;D=EPA-HQ-RCRA-2008-0329-1981.

[19] Resource Conservation and Recovery Act of 1976, Pub. L. 94–580, 90 Stat. 2795, 42 USC 82 part 6901, http://www.gpo.gov/fdsys/pkg/STATUTE-90/pdf/STATUTE-90-Pg2795.pdf.

will be increased incentive to use domestic biomass resources in electricity generation facilities within the United States. Alternatively, the Clean Air Act, Boiler Maximum Achievable Control Technology rule, and Non-Hazardous Secondary Material regulations have the potential to increase the costs of biomass use, including pellet production, by requiring additional pollution abatement practices or technology. The precise impacts of both sets of drivers are currently unknown.

A state-level renewable portfolio standard (RPS) also has the potential to influence pellet consumption for energy production. A summary of these policies and the potential and requirements for wood biomass use from a state RPS are presented as part of the *2014 Annual Energy Outlook* (Bredhoeft and Bowman 2014). The use of woody biomass for energy is still more expensive than the use of other carbon-based fuels, and state-level policies often do not provide subsidies for biomass use. Thus, the cost of biomass energy production may still exceed the cost of producing energy with natural gas even when a penalty is applied. Consumers in the United States have not demonstrated a strong financial commitment to the use of renewable, low-carbon energy (Neff 2012), and thus, utilities have little incentive to pass on added costs to consumers. In addition to state RPS policies, multiple regulations promulgated by or under consideration by EPA will affect how GHG emissions from biomass combustion are accounted for, which may in turn alter behavior and/or state requirements for biomass energy use.

3.5.5 Current and Projected U.S. Wood Demands

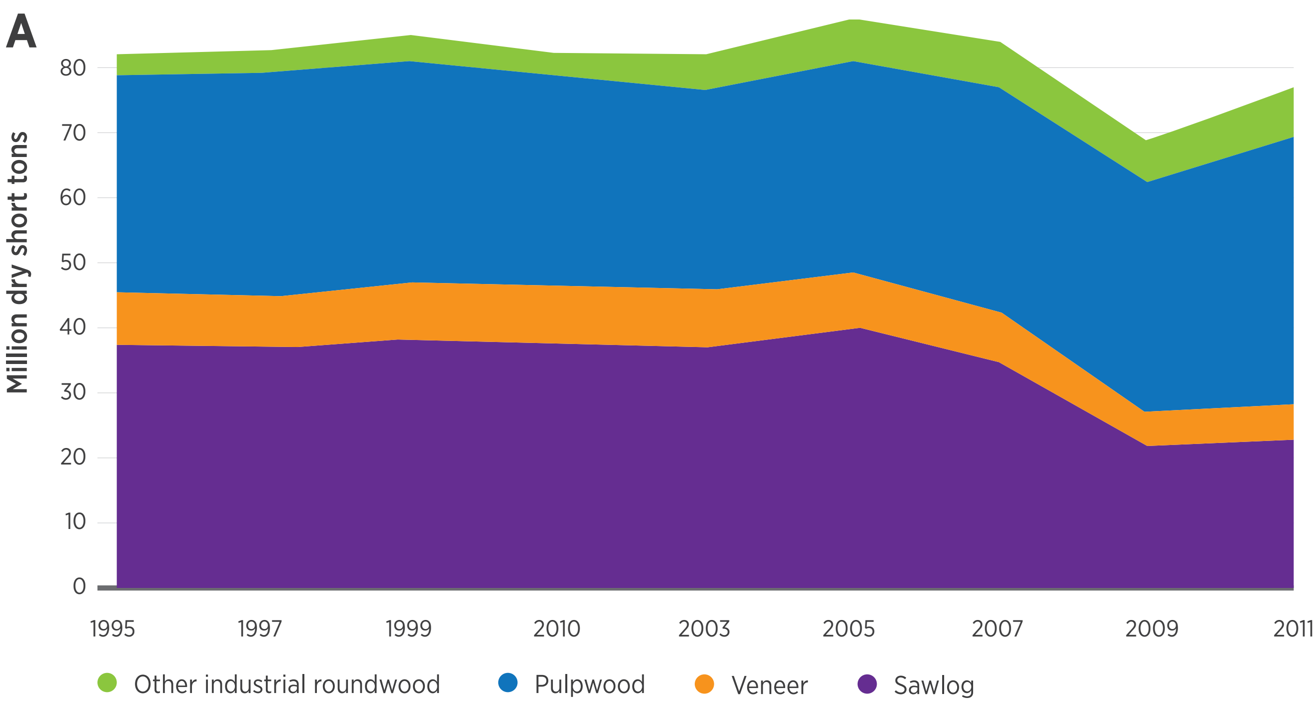
Timber in the U.S. South is harvested and used as inputs to conventional wood products, including the production of lumber, panels, paper products, and posts/poles/pilings. The Forest Service defines these inputs as sawlogs, veneer logs, composites, pulpwood, and a catch-all category called “other industrial roundwood” (USDA Forest Service 2015b). When there are fewer than three facilities producing wood products in any geography, the inputs to their processes are combined into a category referred to as “other industrial roundwood.” Thus, most inputs to pellet production and other energy uses are categorized as other industrial roundwood. Before 2011, however, this was not a notable part of the measured timber use, comprising only about 1% of the total wood use in 2011 and only 2% of small-diameter wood uses (pulpwood and composites) (USDA Forest Service 2015b; Forisk Consulting 2015). Figure 3.22 shows the timber product use data for softwoods and hardwoods, South-wide, for 1995–2011 (not including Texas). Softwoods are the major timber product used (more than 75 million dry short tons through 2007 and in 2011), with a fairly level trend except for the effects of the 2007–2009 recession. In contrast, use of hardwood small roundwood for pulpwood has been declining since 1995, and hardwood sawlog use shows a marked recessionary falloff in use after 2007. Note that both softwood and hardwood veneer log use is declining, as veneer mills have closed across the South. Since 2011, hardwood lumber exports from the South have increased by nearly 60%, which will increase the production level somewhat even if domestic consumption has not recovered.

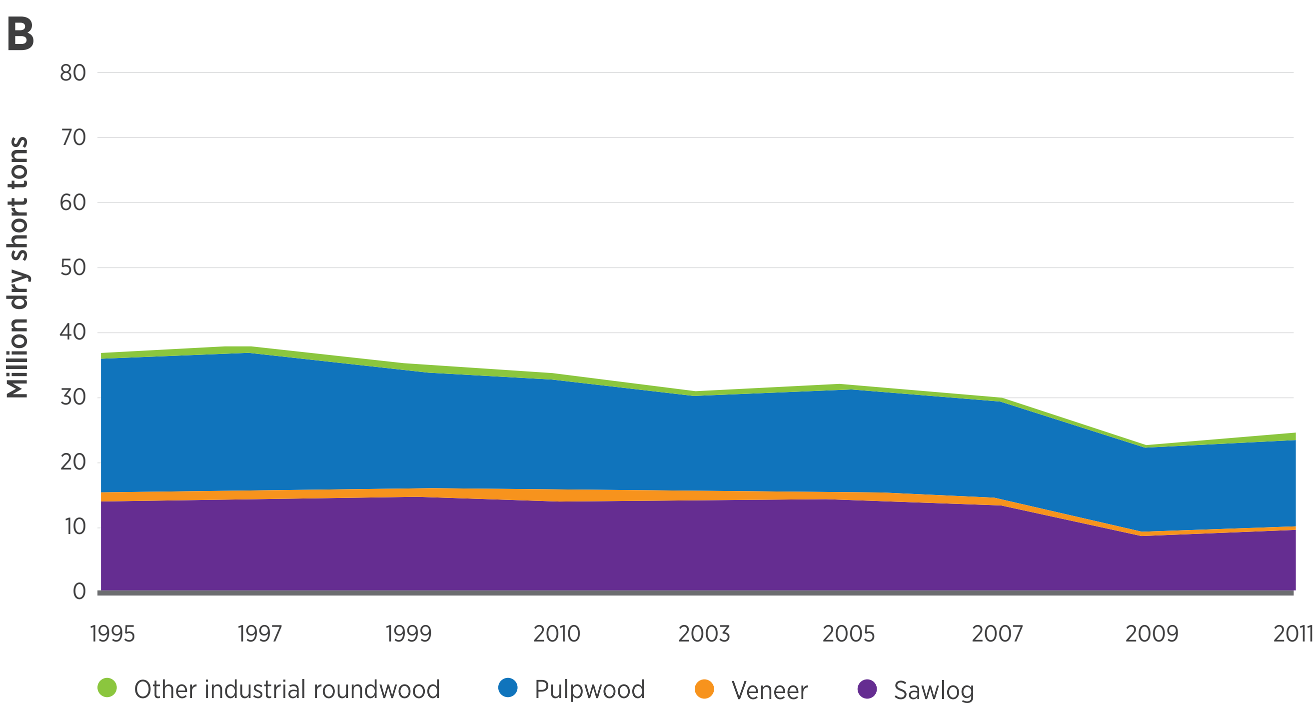
Although U.S. paper manufacturing has declined in recent years (Prestemon, Wear, and Foster 2015), data from 1953 to 2012 on inputs to paper manufacturing in the South indicate that the total use of southern wood for paper has leveled off since 2003 (fig. 3.22*A*) after a decline during the recession years of 2007–2009.[20] The leveling off, however, obscures that a decline in residues and hardwood inputs is counteracted by an increase in softwood inputs (fig. 3.22*B*). Softwood small roundwood inputs to paper manufacturing have increased steadily, rising to their highest level ever in 2011. Figure 3.22*A* also shows

[20] These data are derived from a series of Southern Pulpwood Production Reports, including Bentley and Cooper 2015; Bentley and Steppleton 2013 and 2011; Johnson and Steppleton 2011; Johnson et al. 2010, 2009, and 2008.

the input use per mill, which likely reflects increased output per mill, rising steadily through the years. Thus, although the number of mills has declined by 16% since 2000, total input use declined by only 4%, and softwood small roundwood use increased by 27% over that same time period. This has implications for a potentially growing wood energy sector because the competition for softwood small roundwood has increased, whereas the competition for hardwood small roundwood has decreased.

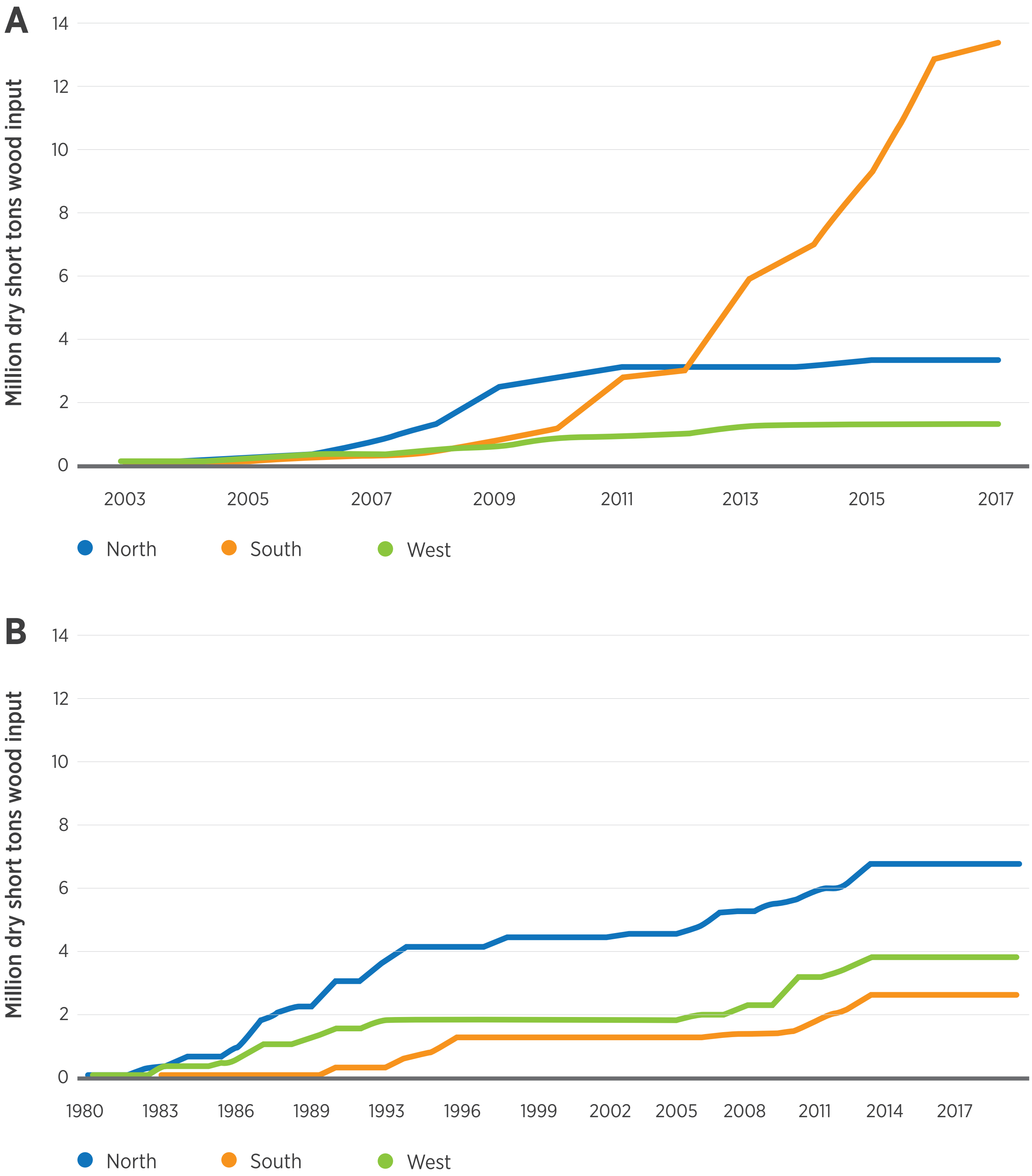
Figure 3.22 | Southern timber product use (excluding Texas), 1995–2011, for (*A*) softwood use and (*B*) hardwood use





Source: Data from USDA Forest Service (2015b).

Figure 3.23 | Historical and projected (announced and meeting screens) wood input use by U.S. region, 2003–2017. *A*, Wood use for pellet production. *B*, Wood use for non-pellet energy production.

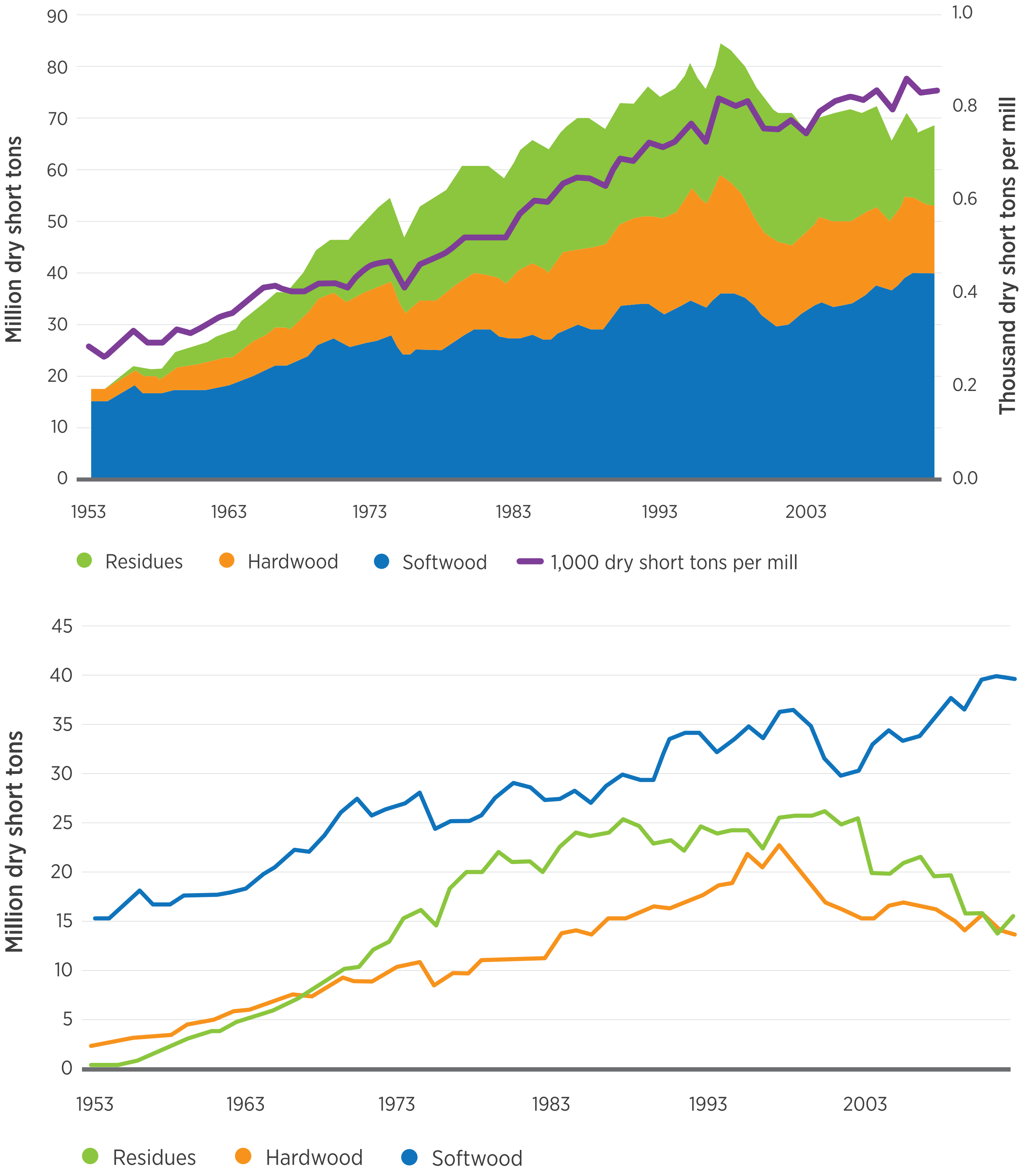


Source: Data from Forisk Consulting (2015).

For the purposes of this analysis, we use the projected pellet and non-pellet wood energy input demands from Forisk Consulting (2015). These inputs are derived from announcements made by energy and pellet producers and through follow-up surveys and analyses conducted by Forisk. The database of all U.S.-announced facilities is updated quarterly and is available by subscription. Generators and producers are asked to specify plant capacity, expected opening date, feedstock source, and progress to completion. Forisk uses various screens and conversion factors to develop the estimated wood input use by source. Note, however, that these feedstock sources are from the generators/producers at the time of announcement and are subject to change as prices and timber conditions in the market change. We did not adjust capacities for lower expected outputs in the starting year in these figures, although in the simulations discussed in this section we did reduce startup year capacities by 50% for each new facility. In this section, we use the Forisk announcements that passed the screens for both technology (uses a commercially viable technology) and status (made recent progress toward completion), which likely represent a more probable set of projects than the full announced list (fig. 3.23).

Figure 3.24*A* shows the actual and projected wood input use for pellet production by U.S. region for 2003–2017. Before 2011, this market was dominated by (mostly bagged) pellet production in the North, but it has since shifted to bulk production in the South. Nearly all of this bulk production is for export—there are few advantages to pelletizing for domestic consumption. In contrast, the wood used for non-pellet domestic energy production is dominated by the North and West, where most of the RPSs have been enacted, although it is not clear how much the RPSs have contributed to these announced facilities (fig. 3.24*B*).

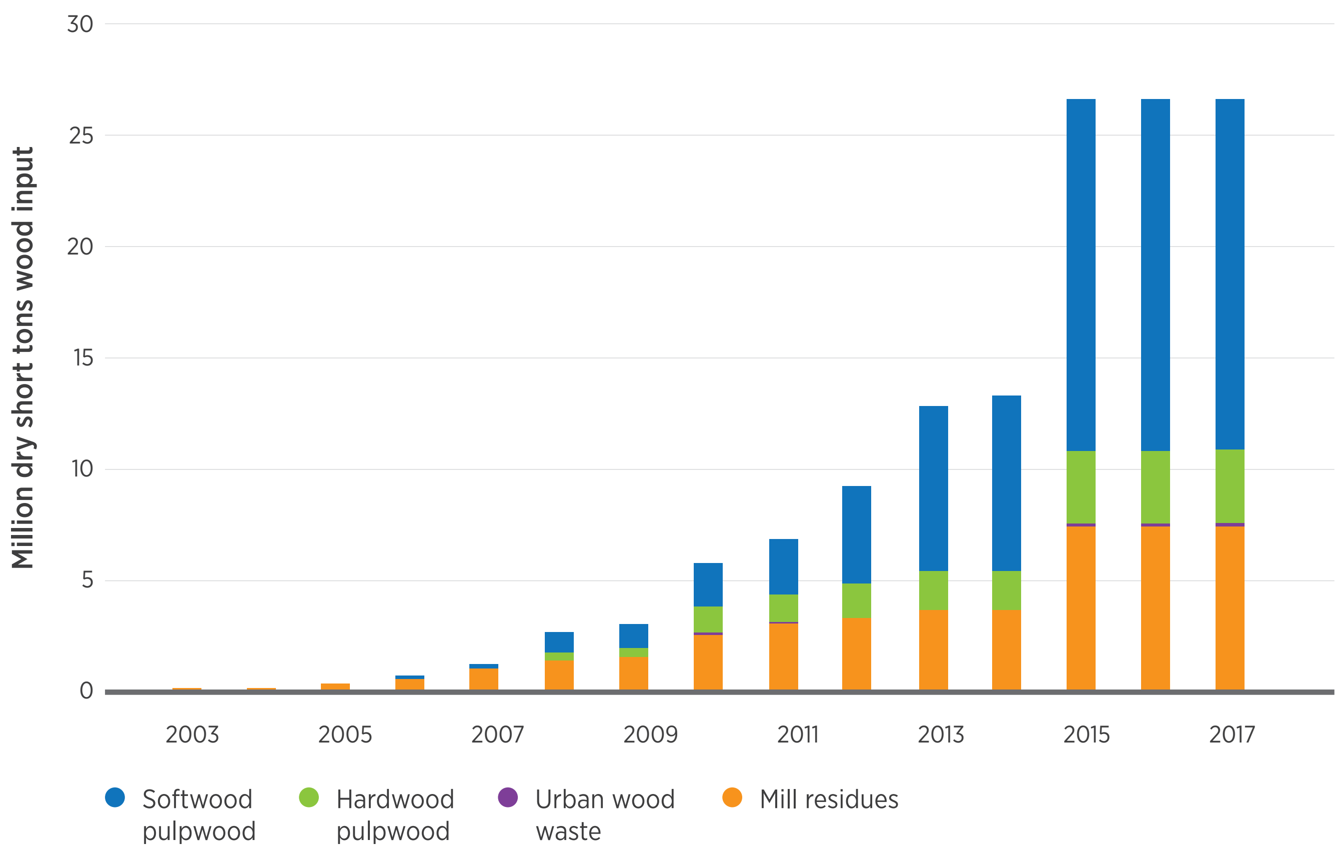
Figure 3.24 | Southern pulpwood production (inputs to paper manufacturing), 1953–2012, by feedstock source and input per mill



Source: These data are derived from a series of Southern Pulpwood Production Reports, including Bentley and Cooper (2015), Bentley and Stapleton (2012; 2013), Johnson and Stapleton (2011), and Johnson et al. (2008; 2009; 2010; 2011).

Inputs to the pellet production process can consist of softwood pulpwood, hardwood pulpwood, mill residues, urban wood waste, and logging residues. Figure 3.25 shows the expected inputs from the announced and screened facilities are dominated by softwood pulpwood, hardwood pulpwood and mill residues. Only very small amounts of input are expected to come from urban wood waste or logging residues.

Figure 3.25 | Historical and announced feedstock source for pellet production, 2003–2017, U.S. South

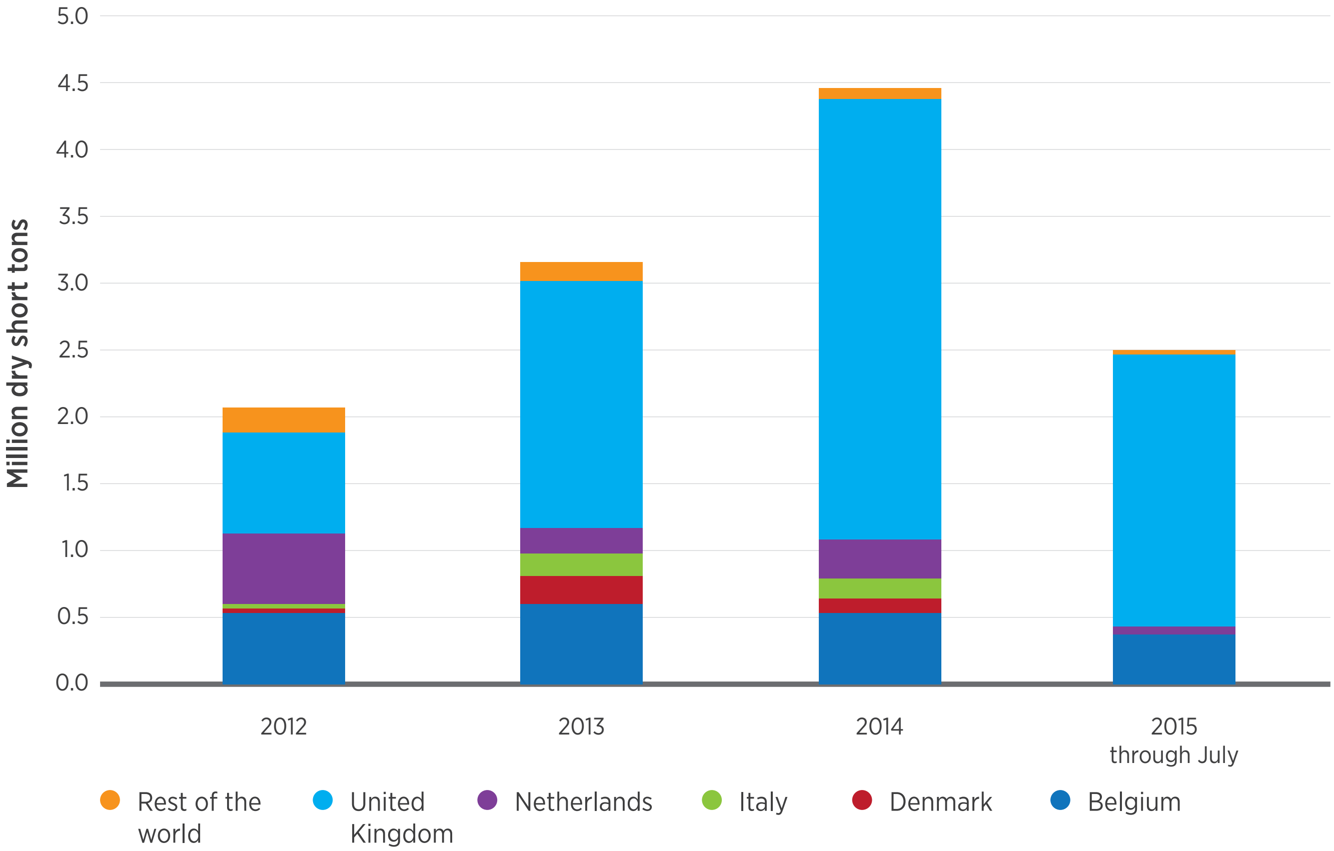


Source: Data from Forisk Consulting (2015).
Note: Quantities of logging residues and urban wood waste are small.

Much of the literature on wood energy assumes that logging residues will play a dominant role as a feedstock (Gan and Smith 2006; Perez-Verdin et al. 2009; Perlack et al. 2005). However, the Forisk survey shows that feedstocks for pellets will more likely be what is called "clean" feedstocks—softwood and hardwood small roundwood and mill residues, with only small amounts of input from logging residues and urban wood waste (fig. 3.25). These predictions from the announcing companies are subject to change, however, if future prices for small roundwood and mill residues rise, or if future prices for logging residues fall.

Output from the production of bulk pellets can be measured in the export statistics. According to the export data from the Bureau of the Census (2015), exports of wood pellets from the United States increased from 2.1 million dry short tons in 2012 to 4.5 million dry short tons in 2014, with more than 99% of those exports coming from southern ports.

Figure 3.26 | Exports of wood pellets from the United States by country of destination for 2012–2015



Source: Data from Census Bureau (2015).

Nearly all of these exports are going to the EU, rising from 94% in 2012 to 99.8% in the first half of 2015. The exports to the EU are dominated by exports to the UK, which increased from 36% of U.S. pellet exports in 2012 to more than 82% of U.S. exports in 2015 (fig. 3.26).

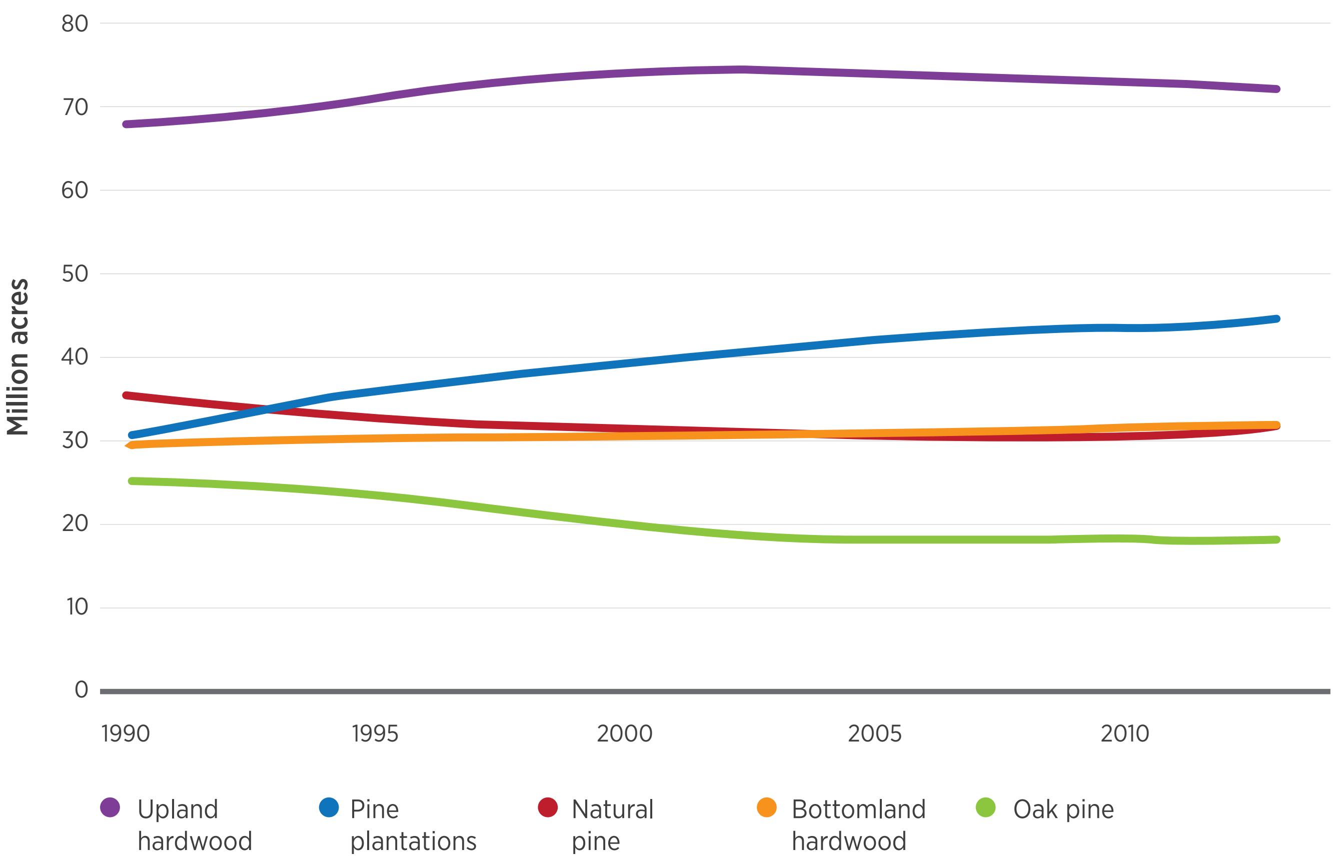
Overall, the pertinent demand factors are (1) the lack of a decline in total pulpwood demand, especially for softwood pulpwood; (2) the substitution of mill residues for small roundwood, making the output of the small roundwood–using sector a function of the demand for large roundwood; (3) the varying levels of large roundwood demand as affected by housing and lumber markets, both past and future; and (4) the influence of policies on the demand for wood pellets (international policies) and the demand for other wood as biomass feedstocks (domestic policies).

3.5.6 Supply Factors

The current and near-term (10–15-year) supply of timber is defined by what is already on the ground, what is harvested in the near term, and growth rates of existing timberland. Beyond 15 years, the supply will be influenced by landowner forest investment decisions (including planting of improved seedlings, intensive silviculture, conversion of nonforest to natural stands, and planting and replanting of pine plantations), as well as the loss of timberland to other land uses. In this section, we evaluate the forest conditions in the South that influence, currently and in the future, the supply of wood for both energy and conventional uses.

From the periodic and annual inventory records of the 13 southern states, we model[21] the South-wide timberland area by broad management type (fig. 3.27), inventory by species group (fig. 3.28), and annual removals and growth by species group (fig. 3.29). The broad management types are pine plantations, natural pine, oak-pine, upland hardwood, and bottomland hardwood; and the species groups are softwood and hardwood. Age class distribution area and inventory affect the current ability of the forest to respond to changes in demand (such as an increase in feedstock use for wood energy production), which in turn will affect the future response.

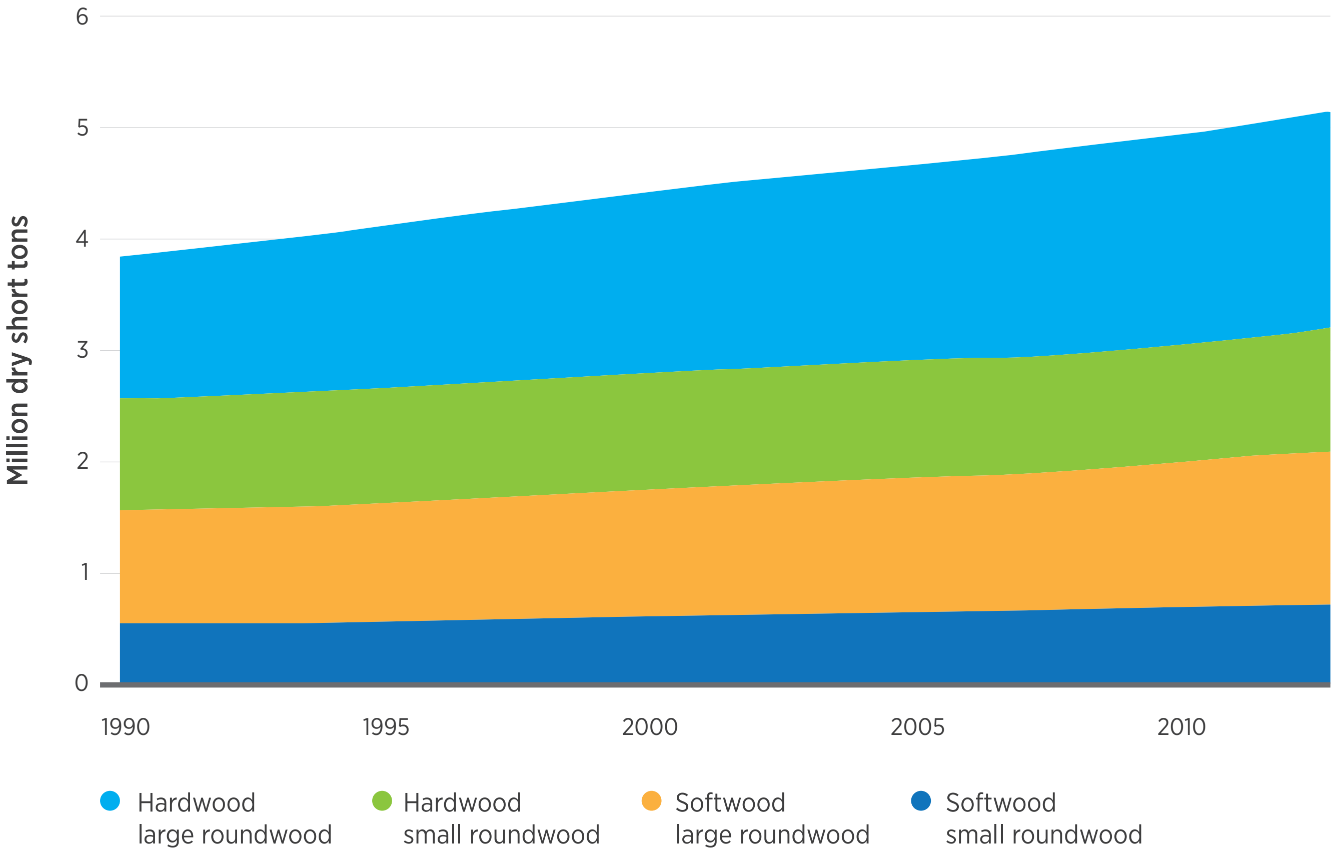
Figure 3.27 | Southern timberland acres by broad management type, 1990–2013 (excluding Kentucky)



Source: Data from SOFAC (2015) and USDA Forest Service (2015a).

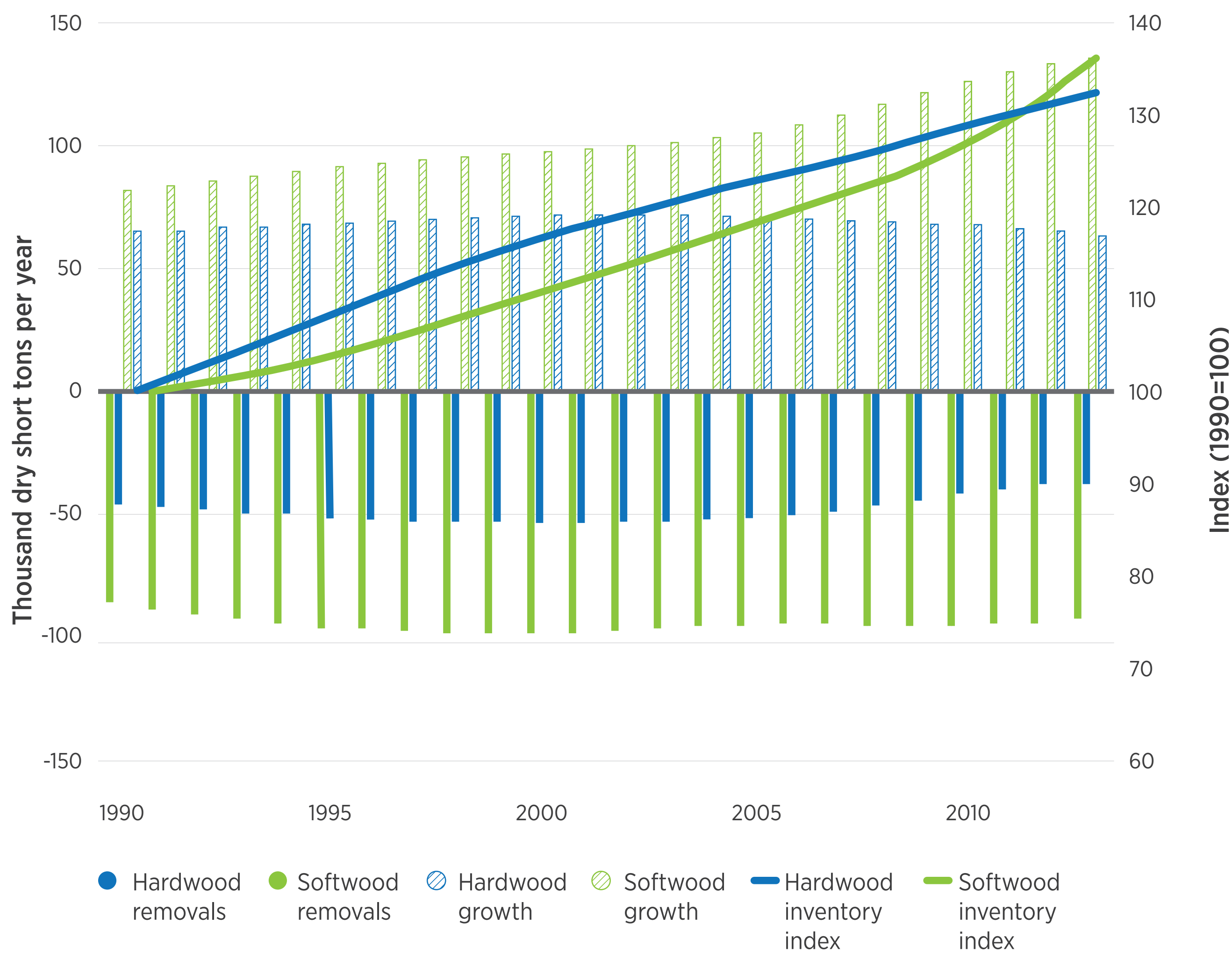
[21] We use Statistical Analysis System Proc Expand to fill in the between-survey-year estimates using a cubic spline function. This is for illustrative purposes only—these data are inadequate for use in any statistical modeling.

Figure 3.28 | Southern growing stock inventory, 1990–2013 (hardwood small ≤11 in. dbh, softwood small ≤9 in. dbh; excluding Kentucky)



Source: Data from SOFAC (2015) and USDA Forest Service (2015a).

Figure 3.29 | Southern growing stock growth and removals from timberland, and an inventory index, by species group, 1990–2013 (excluding Kentucky)



Source: Data from SOFAC (2015) and USDA Forest Service (2015a).

Overall, timberland area between 1990 and 2013 has been relatively stable, and large increases in pine plantations have generally been offset by declines in natural pine area.[22] Timber inventory, however, has been increasing steadily over this same time span—with hardwood inventories increasing by 32% and softwood inventories increasing by 36% (fig. 3.30). This picture of southern timberland area, however, obscures both the age class dynamics and the competing forces that could lead, all else held equal, to declining timberland area (increased agricultural rents or increased urbanization) or to increasing timberland area (increased timberland rents) (Hardie et al. 2000; Lubowski, Plantinga, and Stavins 2008). Given that urban land area is known to have increased over this time period, and that timber rents cannot realistically compete with

[22] Note that a data inconsistency in 2003–2004 in Kentucky led to exclusion of Kentucky from the area, inventory, growth, and removals charts; and incomplete timber product output data for Texas led to exclusion of Texas from the products discussion, although Texas is included in the Southern Pulpwood Production data.

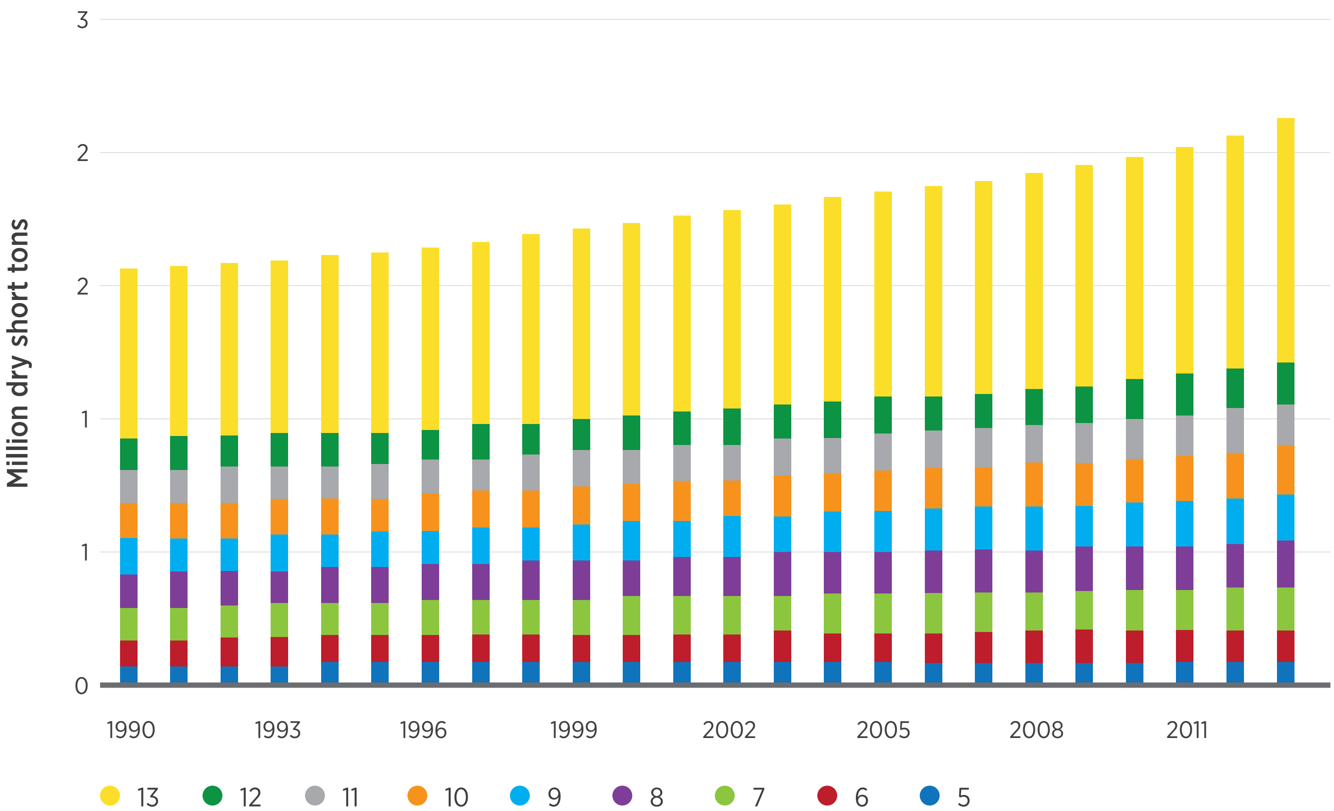
land values for development, the small changes in total timberland area imply that conversions of agricultural or pasture land into timberland have offset some or all of the declines in timberland area.

The age class dynamics can be seen, to some extent, by examining the changes in inventory by the size class of trees (fig. 3.30). Hardwood inventories are classed as large if they have >11 inches dbh and small otherwise; softwood inventories are classed as large if >9 inches dbh and small otherwise. Small-diameter hardwood inventory volume has increased at a rate of less than 0.03% rate per year since 1990, whereas large-diameter hardwood inventory has increased at a rate of more than 1.7% per year over 24 years, although this rate has fallen more recently (1% per year from 2005 to 2013). These data likely indicate that growth is slowing in older stands and that fewer acres have reverted to hardwoods in more recent years.

Softwood inventories, both large and small diameters, have increased at fairly steady rates of about 1% per year, although the softwood average annual rate of increase is nearly twice as high in recent years (2005–2013 compared with 1990–2005) (fig. 3.30). The overall increases can be attributed, in part, to the use of improved genetic stock and advanced silvicultural techniques. The more recent accelerated increase in softwood inventories is partly due to accumulating inventory in the larger diameter classes.

Figure 3.29 shows hardwood and softwood removals and growth in dry short tons per year (on the left axis) and an index of softwood and hardwood inventory (on the right axis). South-wide, (excluding

Figure 3.30 | Southern softwood growing stock inventory on timberland by diameter class (inches dbh), 1990–2013 (excluding Kentucky)



Source: Data from SOFAC (2015) and USDA Forest Service (2015a).

Kentucky), removals of both hardwood and softwood show the effects of the recession of 2007–2009. The rapid recent growth rates for softwood reflect the factors noted earlier as contributing to inventory gains. Growth rates for hardwood have returned to below 1990 levels after a brief spell at a higher rate. The recent decline in hardwood growth and the leveling off of hardwood removals can be seen in the leveling of the hardwood inventory index in more recent years.

These data show that timberland area has changed little over the last 24 years, but that the composition of timberland includes more planted timberland than in 1990. And more recently, hardwood removals are down, as are hardwood growth quantities. Timber inventories appear to be accumulating in the larger and older classes, in part because of the decline in use during and following the 2007–2009 recession. Although the increase in inventory and stable timberland area could be arguments for the use of timber in wood energy, there will likely be effects on existing markets, landowners, and forests.

3.5.7 Market Issues and Analysis

To illustrate the potential effects of an increase in wood energy demand under varying timber supply conditions, we use a partial equilibrium timber market model to show how price, removals, and inventory for different size and species of roundwood, as well as timberland, evolve over time in response to an increase in wood energy demand. The SRTS model (Abt, Cubbage, and Abt 2009) is used to evaluate a southern pellet supply region (U.S. Coastal South) as well as three smaller subregions of the South that have differing supply and demand characteristics. The subregions include the Gulf Coast (parts of Texas and Mississippi and all of Louisiana), the Mid-Atlantic Coast (parts of North Carolina and Virginia and all of South Carolina); and the Southeast Coast (parts of Georgia, Alabama, and Florida). More details on the modeling and the simulations can be found in Abt et al. (2014).

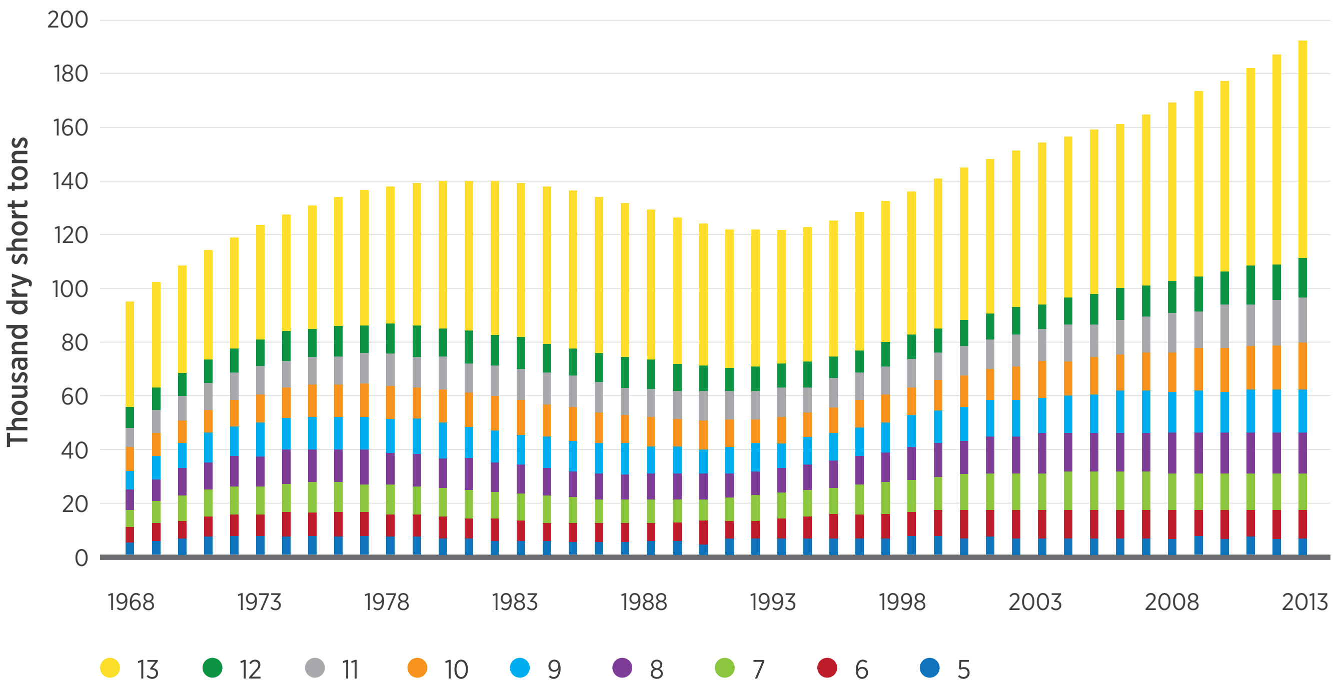
We use the historical data and the SRTS projections from Abt et al. (2014) to highlight the interactions between increasing wood energy demands and subregional specific timber supply factors and projected prices, inventory, and removals by species group and roundwood category (small or large). Using the announced facilities to represent potential demand for wood for energy (including pellets for both export and domestic wood energy), we compare two wood energy scenarios—a baseline scenario, which holds wood biomass feedstocks demand at 2010 levels, and an increased wood energy scenario. Both scenarios include constant demand for non-energy pulpwood and a moderately increasing demand for sawtimber, which are designed to reflect post-recession recovery levels.

3.5.8 Competing Pulpwood Demands—Mid-Atlantic Coast

The story of the Mid-Atlantic Coast is one of many little changes—closure of mills using hardwood pulpwood; an influx of new hardwood pellet manufacturers; increased exports of hardwood lumber to China; a Conservation Reserve Program planting boom; and a new panel milling industry. The sum total of these changes, even before the advent of the pellet industry, appeared to be rising removals of softwood small roundwood and falling removals of hardwood small roundwood. Outside the forestry sector, the growth in population and development along the I85/95 corridors and along the coast also have the potential to influence future timber markets in this area.

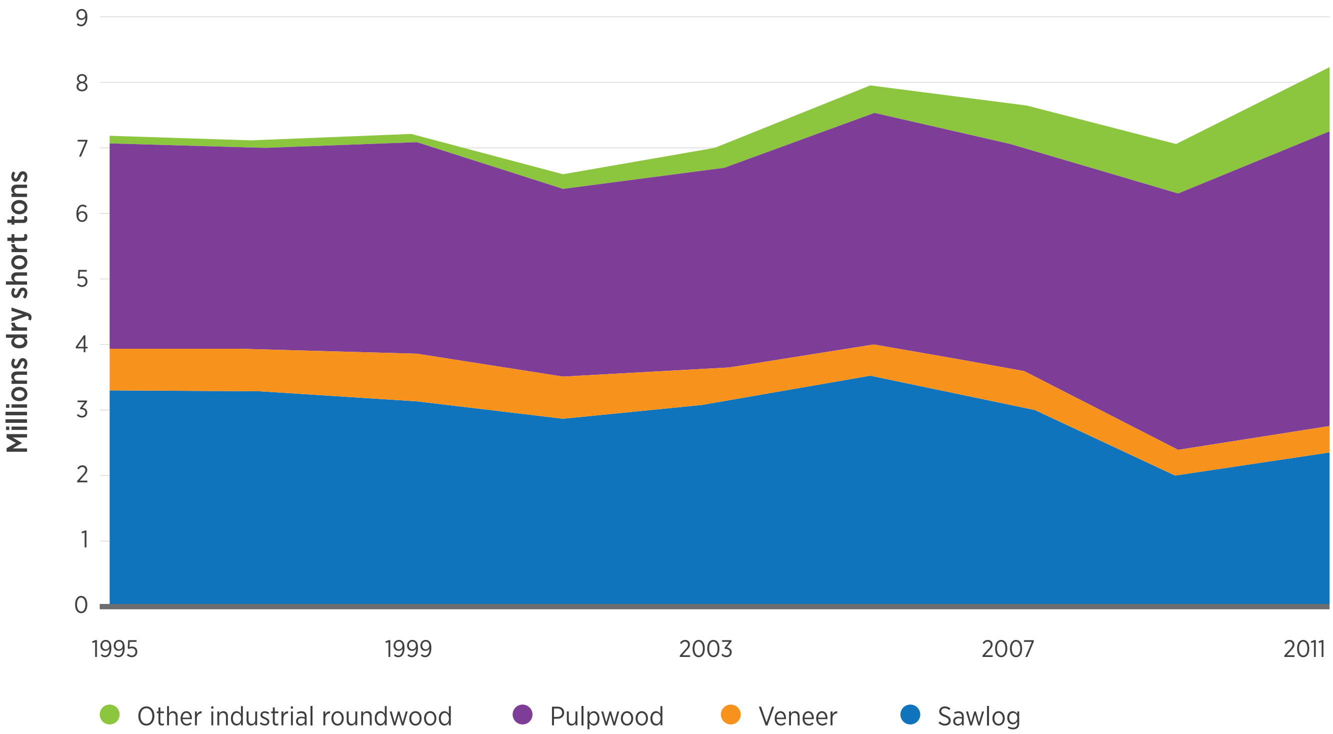
South Carolina is currently confronted with a fairly constant softwood small roundwood inventory (fig. 3.31) and rising softwood small roundwood demand (fig. 3.32). This combination of level small-diameter softwood production from forests, and increasing softwood small-diameter roundwood use (up 29% since 2005), would be expected to lead to increases in softwood pulpwood prices.

Figure 3.31 | Softwood growing stock inventory in South Carolina by diameter class (inches dbh), 1968 to 2013



Source: Data from SOFAC (2015) and USDA Forest Service (2015a).

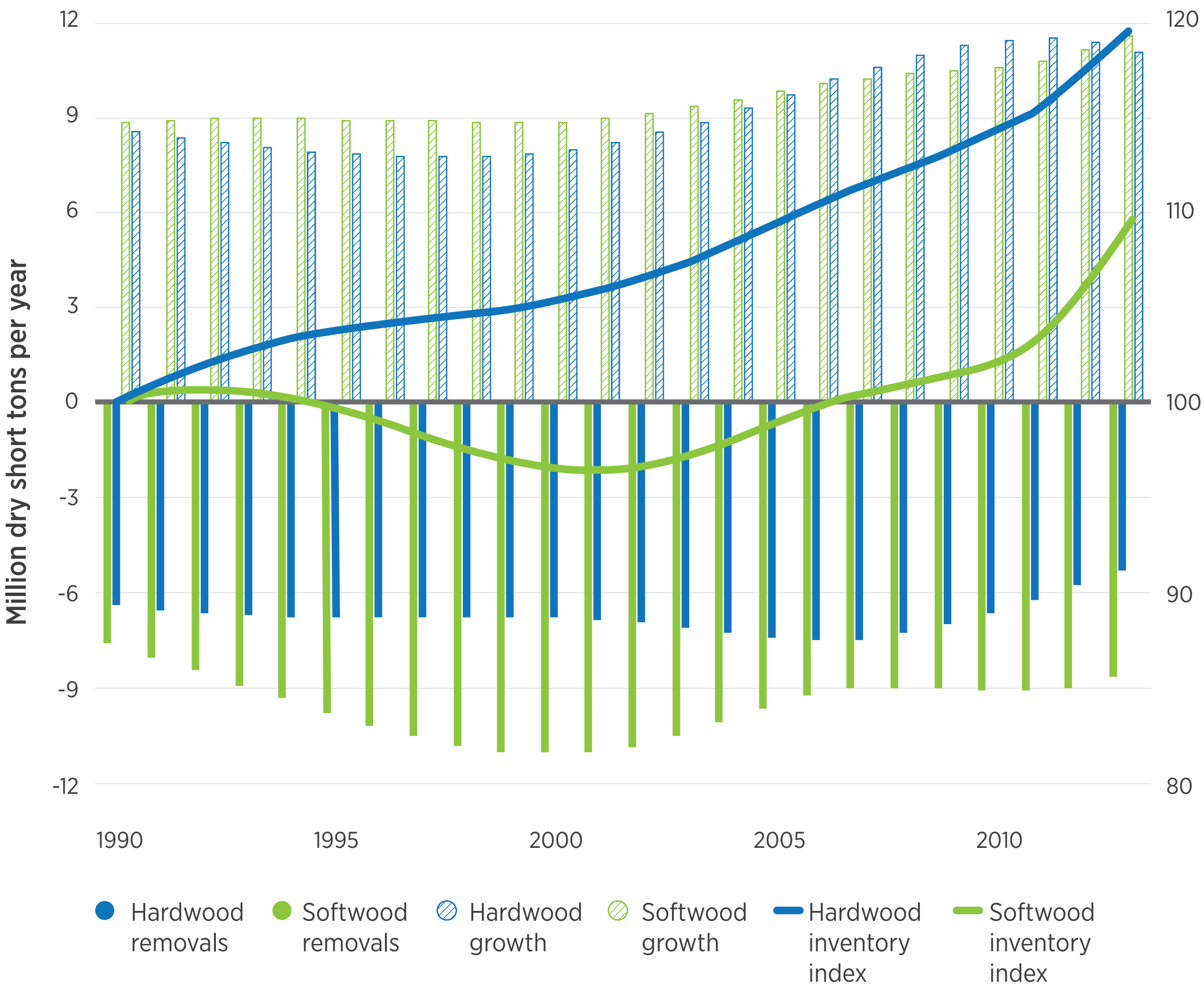
Figure 3.32 | South Carolina softwood timber product use, 1995–2011



Source: Data from USDA Forest Service (2015b).

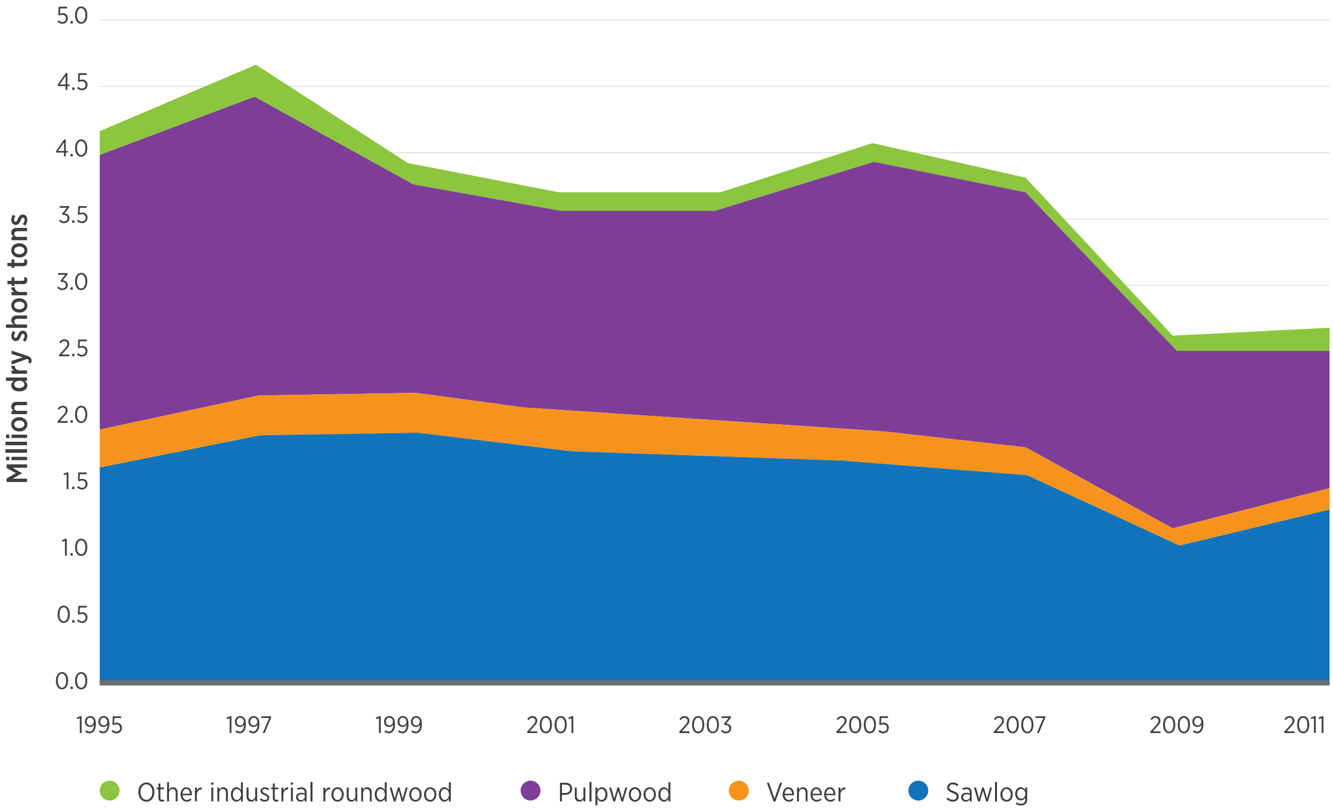
North Carolina illustrates a different situation, in which recent declines in hardwood growing stock removals (fig. 3.33) are reflected in declines in hardwood pulpwood use (fig. 3.34). This is leading to some increases in hardwood inventory—the hardwood inventory index shows a 20% increase since 1990. Softwood harvests were greater than softwood growth between 1995 and 2005 and led to the softwood inventory index falling below 100 for those years. Since then, however, reductions in removals and increases in growth have led to a 10% increase in softwood inventory over the 1990 values.

Figure 3.33 | Average annual growing stock growth and removals in North Carolina, and inventory index values for hardwood and softwood, 1990–2013



Source: Data from SOFAC (2015) and USDA Forest Service (2015a).

Figure 3.34 | North Carolina hardwood timber product use, 1995–2011

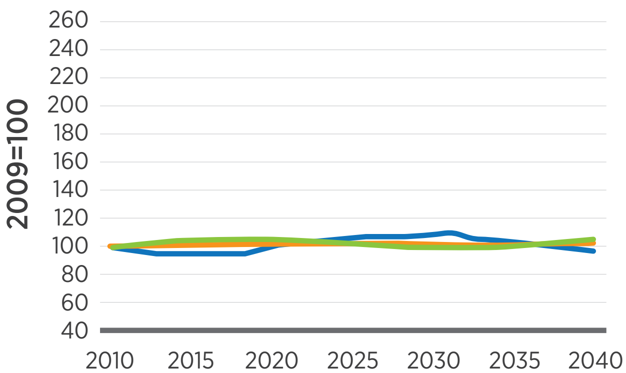


Source: Data from USDA Forest Service (2015b).

Projecting the current situation with modest increases in conventional products out to 2040, and no increase in wood biomass feedstocks use in the Mid-Atlantic coast region, results in a stable outlook for softwood small roundwood removals, prices, and inventory (fig. 3.35*A*). Projecting an increase in energy demand for softwood, however, leads to more than a doubling of stumpage prices and an accompanying increase in removals and decrease in inventory in the middle years of the projection (fig. 3.35*B*). The price and inventory recovery occur because the model assumes higher product prices lead to increased planting and increased timberland area; so after about 2025, available inventory rises and prices begin to fall. For small hardwoods in the baseline scenario, the decline in historical use contributes to continuing increases in inventory, with prices declining (fig. 3.35*C*). Projecting an increase in hardwood feedstock demand, however, results in increases in prices and harvest, and a slowing in the increase in inventory, though these are small relative to changes in the softwood market (fig. 3.35*D*).

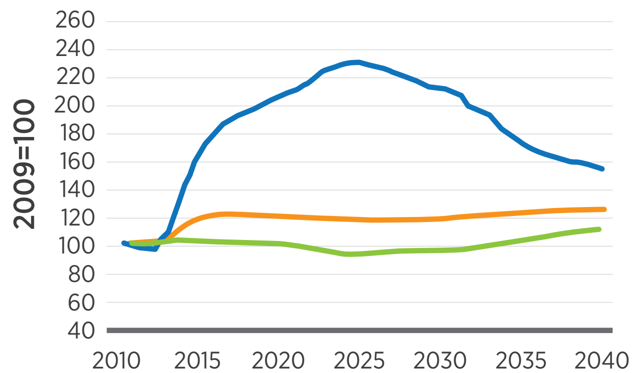
Figure 3.35 | Mid-Atlantic Coast projection results showing inventory, removals, and price indices for small roundwood for 2010–2040 for both the baseline and wood energy scenarios and both softwood and hardwood

A



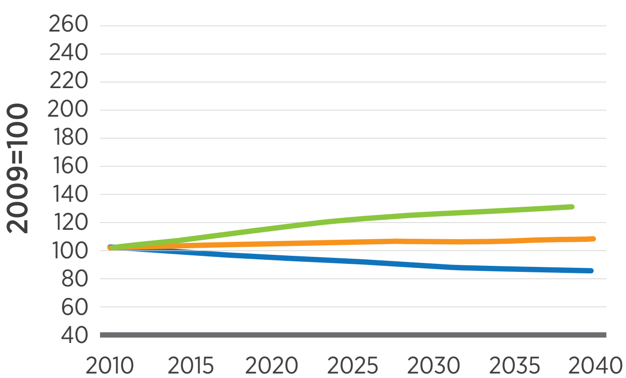
Baseline scenario: softwood small roundwood

B



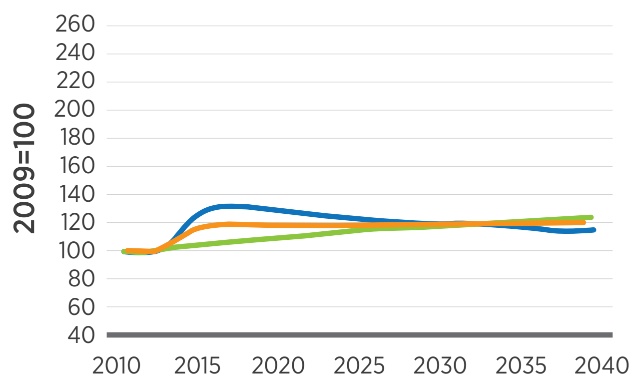
Wood energy scenario: softwood small roundwood

C



Baseline scenario: hardwood small roundwood

D



Wood energy scenario: hardwood small roundwood

● Inventory ● Removals ● Price

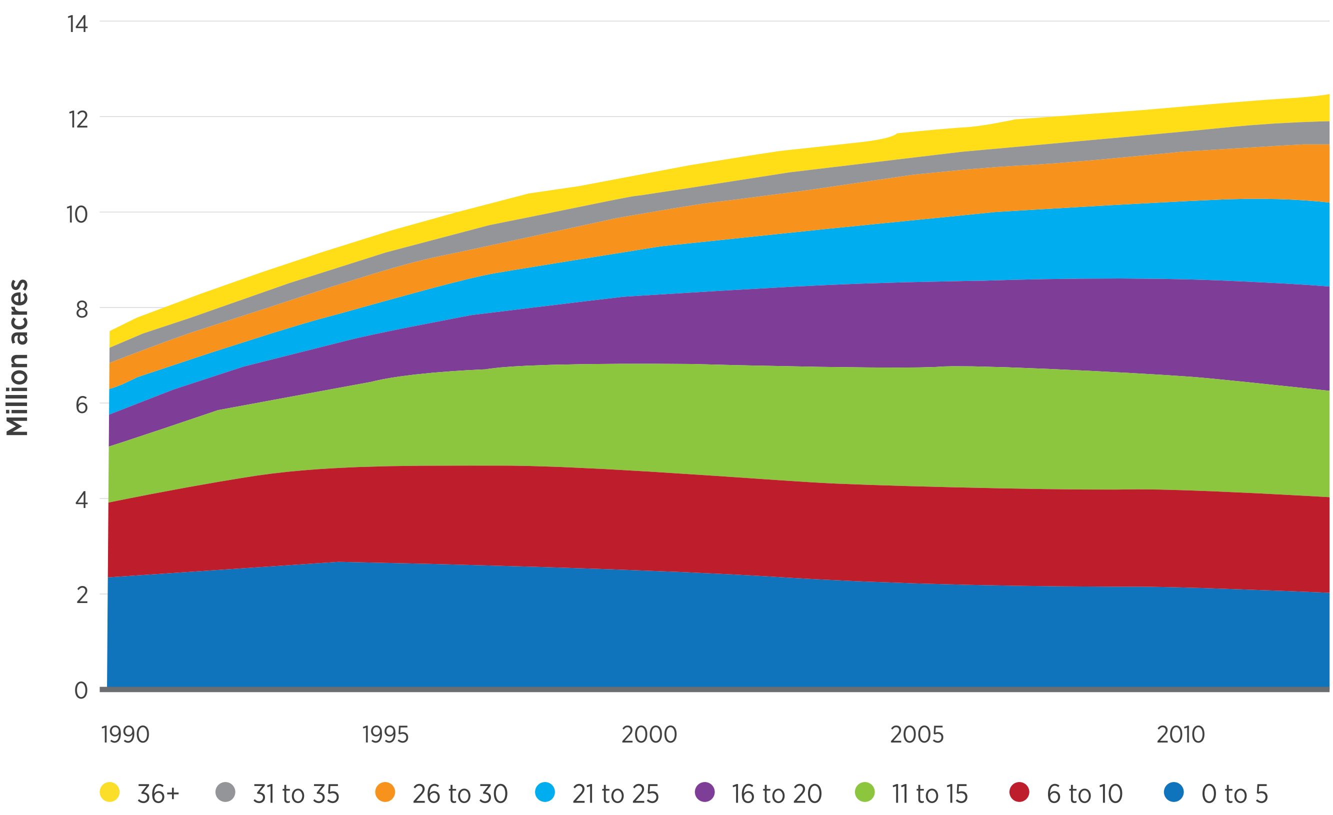
3.5.9 Decline in Sawtimber Harvest (the Sawtimber Overhang)—Gulf Coast

This region comprises the entire state of Louisiana, all but the Delta region of Mississippi, and the southeast coastal survey unit of Texas. The story in this region is the accumulation of softwood large roundwood inventory, sometimes called a "sawtimber overhang." The overhang results from a combination of two factors—a planting boom in the late 1980s (at least partially due to increased planting because of the Conservation Reserve Program) and a decline in harvest (at least partially due to the decline in sawtimber demand for housing since the start of the 2007–2009 recession).

Figure 3.36 shows the pine plantation acres by 5-year age classes in this subregion. The acres in the youngest age class (0–5 years) have been declining since 1995, and there are no acres in the oldest age classes (greater than 60, not specified in figure) before 2003—the pine plantation inventory average age is getting older. From 1990 to 2013, the acres in the 0–5-year age classes have declined by 7% while the acres in the older age classes have increased by 26%.

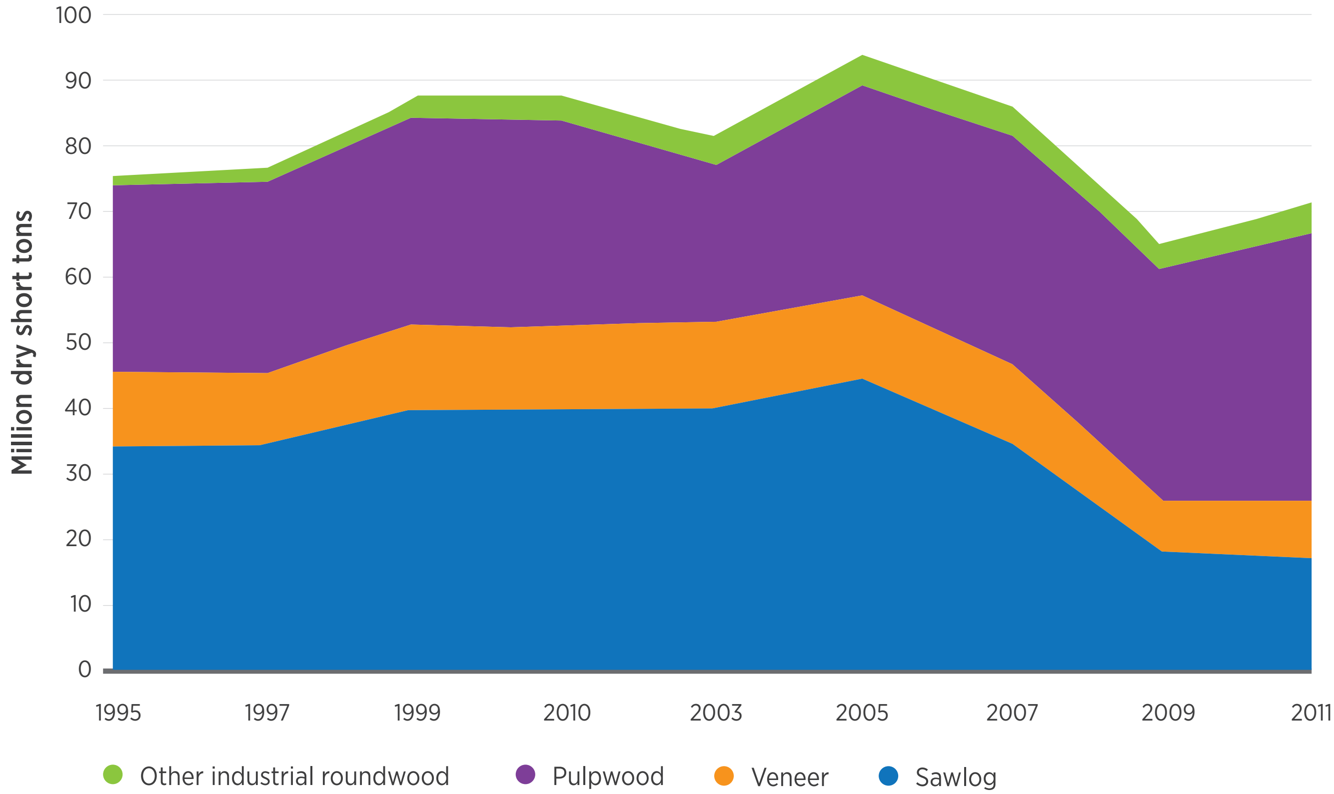
The use of this aging pine resource, however, has declined since 2005 and has not recovered following the recession (fig. 3.37). Between 1995 and 2005, sawlog use increased at an annual rate of 1.5%. Since then, however, sawlog use has decreased at 5.5% per year. As inventory accumulates in the large roundwood size because of lower demand, fewer acres are being planted because the lower sawtimber prices reduce expected landowner rents and fewer are willing to plant. In addition, with fewer final harvests, there are fewer areas available to plant.

Figure 3.36 | Pine plantation acres in Gulf Coast subregion by 5-year age classes, 1990–2013



Source: Data from SOFAC (2015) and USDA Forest Service (2015a).

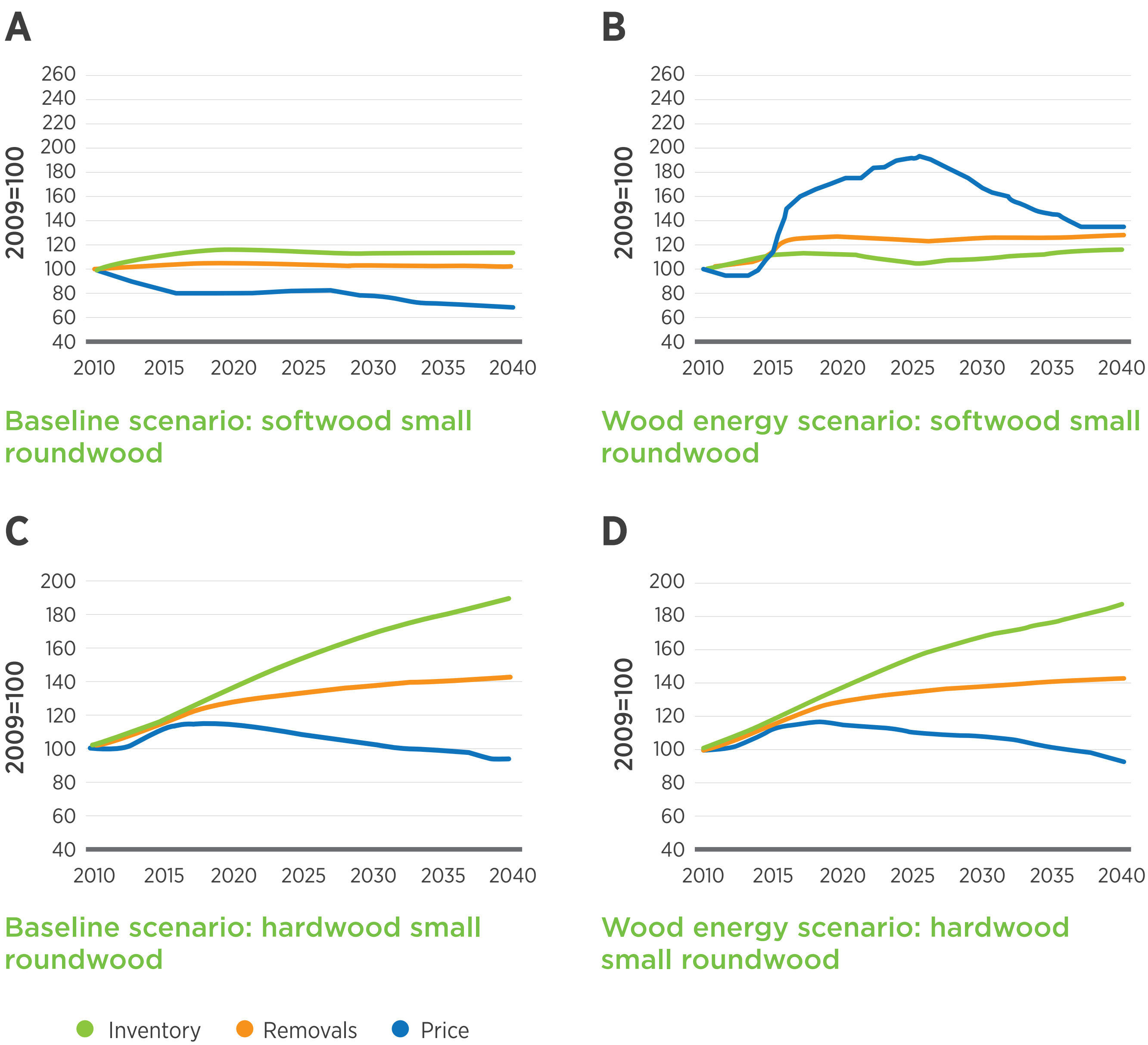
Figure 3.37 | Softwood timber product use in the Gulf Coast subregion (excluding Texas), 1995–2011



Source: Data from USDA Forest Service (2015b).

Projections of softwood small and large roundwood prices, removals, and inventory for this region, with and without additional wood biomass feedstocks demands, are shown in figure 3.38. The baseline scenario shows that both small (fig. 3.38*A*) and large (fig. 3.38*C*) roundwood inventories continue to increase and prices continue to fall. When increased wood energy demands are projected, however, figure 3.38*B* and *D* show that even as softwood small roundwood prices rise with the addition of new wood energy demands, there is almost no effect on softwood large roundwood markets. Even with increased harvests, the low large roundwood prices reduce landowner rents and so reduce incentives to plant trees either on recently harvested land or on converted agricultural land.

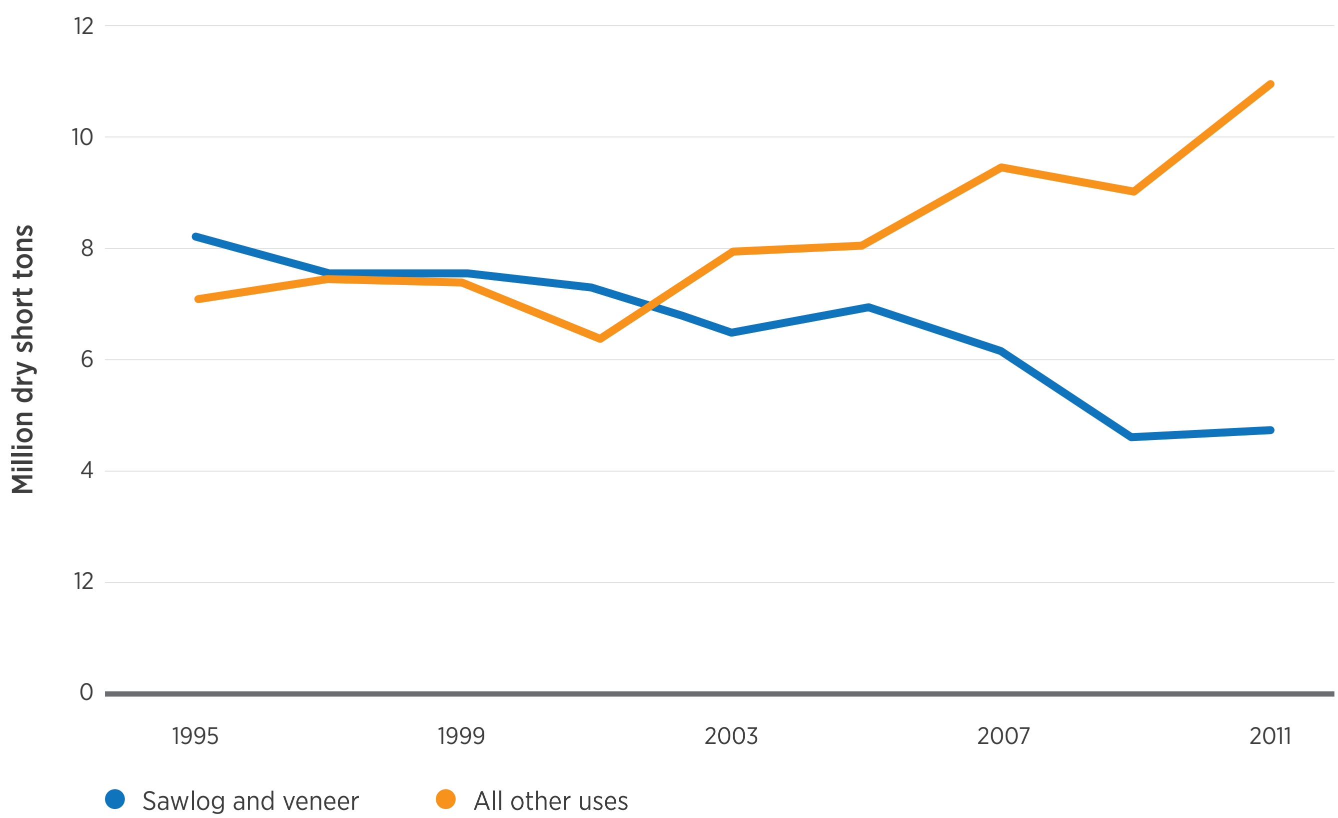
Figure 3.38 | Gulf Coast projection results showing inventory, removals, and price indices for softwood roundwood for 2010–2040 for both the baseline and wood energy scenarios



Projected Recovery in Sawtimber Demand—Southeast Coast

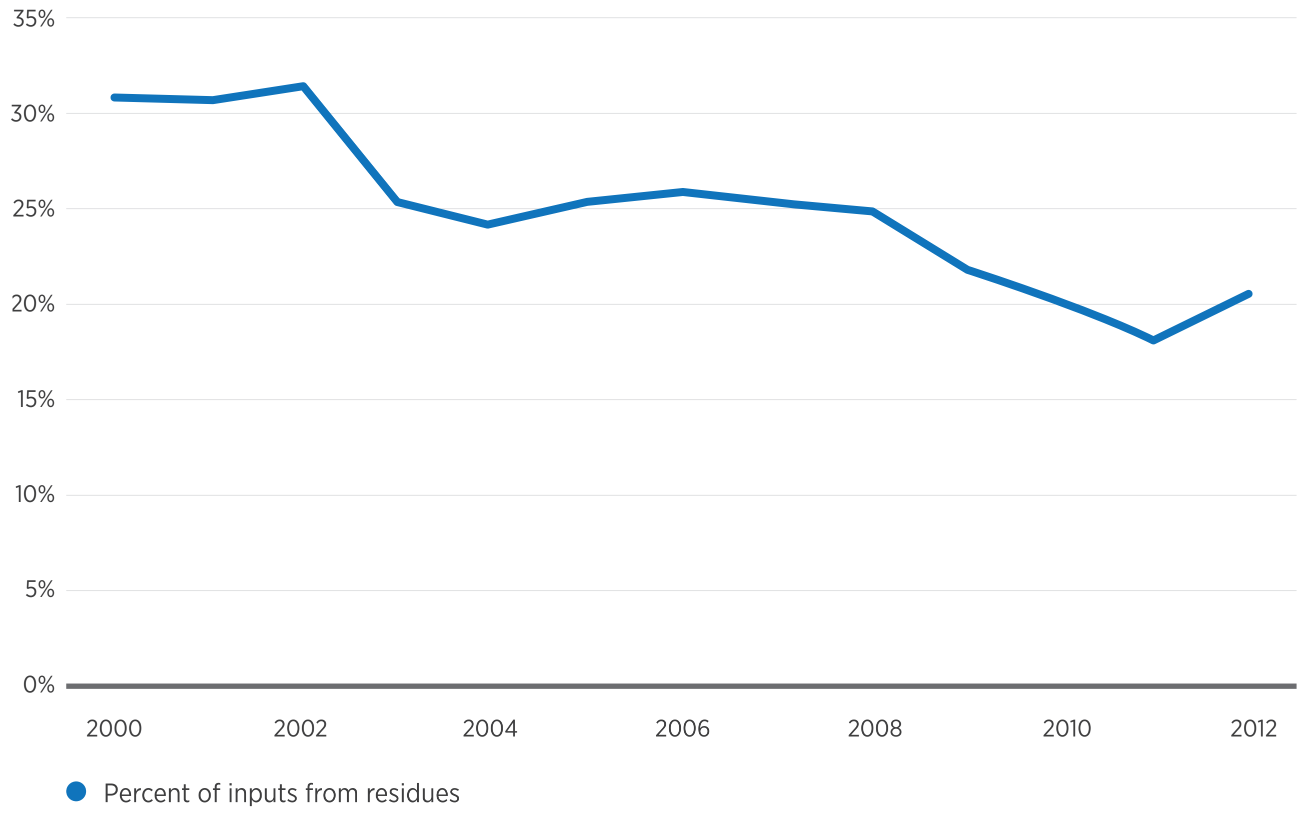
The Southeast Coastal region can be characterized by its productive forests and active markets for both small and large softwood roundwood. Similar to the other regions, this region had a significant falloff in use of sawlog and veneer timber diameter inputs (fig. 3.39) following the recession, while at the same time timber production for all other uses increased. Because national paper production did not increase during this period, we assume that the increase in small roundwood use was due to the decreased availability of sawmill residues—a result of decreased lumber demand for housing. Figure 3.40 shows the proportion of southern pulp mill wood input demand that was met by a combination of mill residues and remote chip mills from 2000 to 2012. The decline in 2002–2003 can be attributed, in part, to a decline in the use of remote chip mills, combined with an increase in composite panel production, which uses mill residues. The proportion of wood input met with residues continued to decline through the recession.

Figure 3.39 | Georgia softwood timber product use, 1995–2011



Source: Data from USDA Forest Service (2015b).

Figure 3.40 | Residue and chip use as a percent of total wood inputs to pulp production, U.S. South, 2000–2012



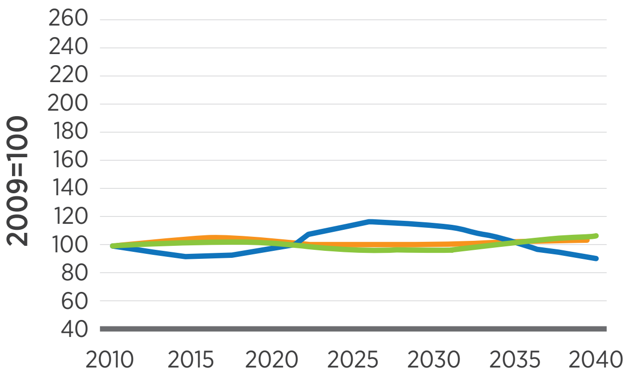
Source: Data from Bentley and Cooper (2015) and Bentley and Steppleton (2013).

In the projections for the Southeast Coast, we assume a 30% feedback between large roundwood input to sawmills, and residues. The actual rate of residue production depends on the diameter of the inputs to sawmills—larger diameter trees lead to lower levels of sawmill residue production. This means that regions where larger diameters of either hardwoods or softwoods are milled to lumber will have lower levels of residue production per unit of sawtimber input. The Southeast Coast has the lowest average diameter inputs in the South and thus has a higher rate of residue feedback. With a 30% feedback of mill residues to pulp or energy production, total sawmill residues from this region amount to between 7% and 10% of total wood energy demands. Thus, an increase in sawmill production would lead to further reductions in the impacts of net wood energy on the forest. This, in turn, would reduce the price pressure and the effect on small roundwood removals and inventory, but would also reduce the ultimate effect on timberland rents and thus reduce the effect on timberland area.

The baseline scenario (fig. 3.41*A*) projects that prices, inventory, and removals of softwood small roundwood stay fairly constant, consistent with the constant level of demand, while fluctuating slightly as inventories and prices rise and fall and removals fall and rise. The wood energy scenario shows more than a doubling of prices, higher removals, and lower inventories because of increased demand for wood biomass feedstocks (fig. 3.41*B*). Figure 3.41*C* and *D* show that the harvest of sawtimber is little affected by the increased wood energy demands, although there is some response in future years as timberland area increases in response to higher timberland rents under the wood energy scenario.

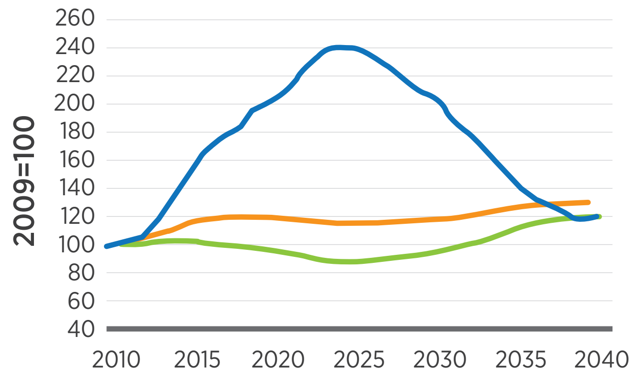
Figure 3.41 | Southeast Coast projection results showing inventory, removals, and price indices for softwood roundwood for 2010–2040 for both the baseline and wood energy scenarios

A



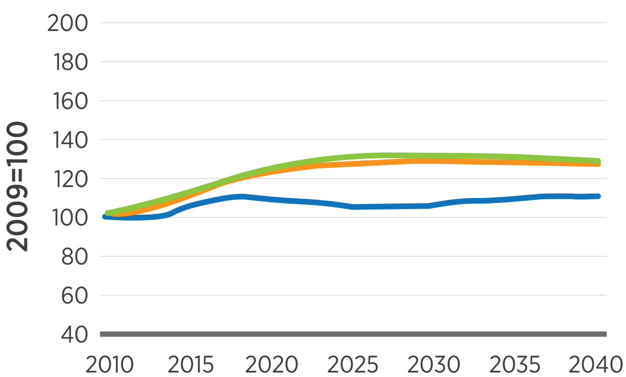
Baseline scenario: softwood small roundwood

B



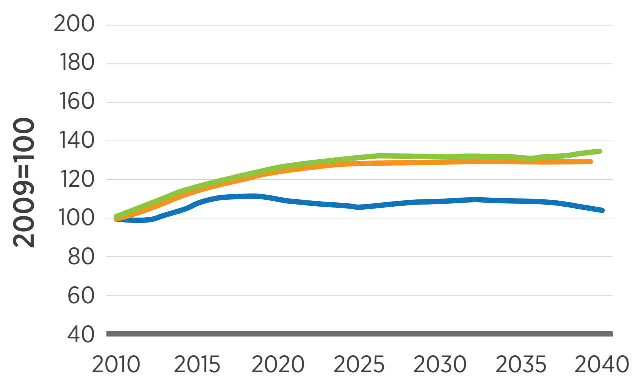
Wood energy scenario: softwood small roundwood

C



Baseline scenario: softwood large roundwood

D



Wood energy scenario: softwood large roundwood

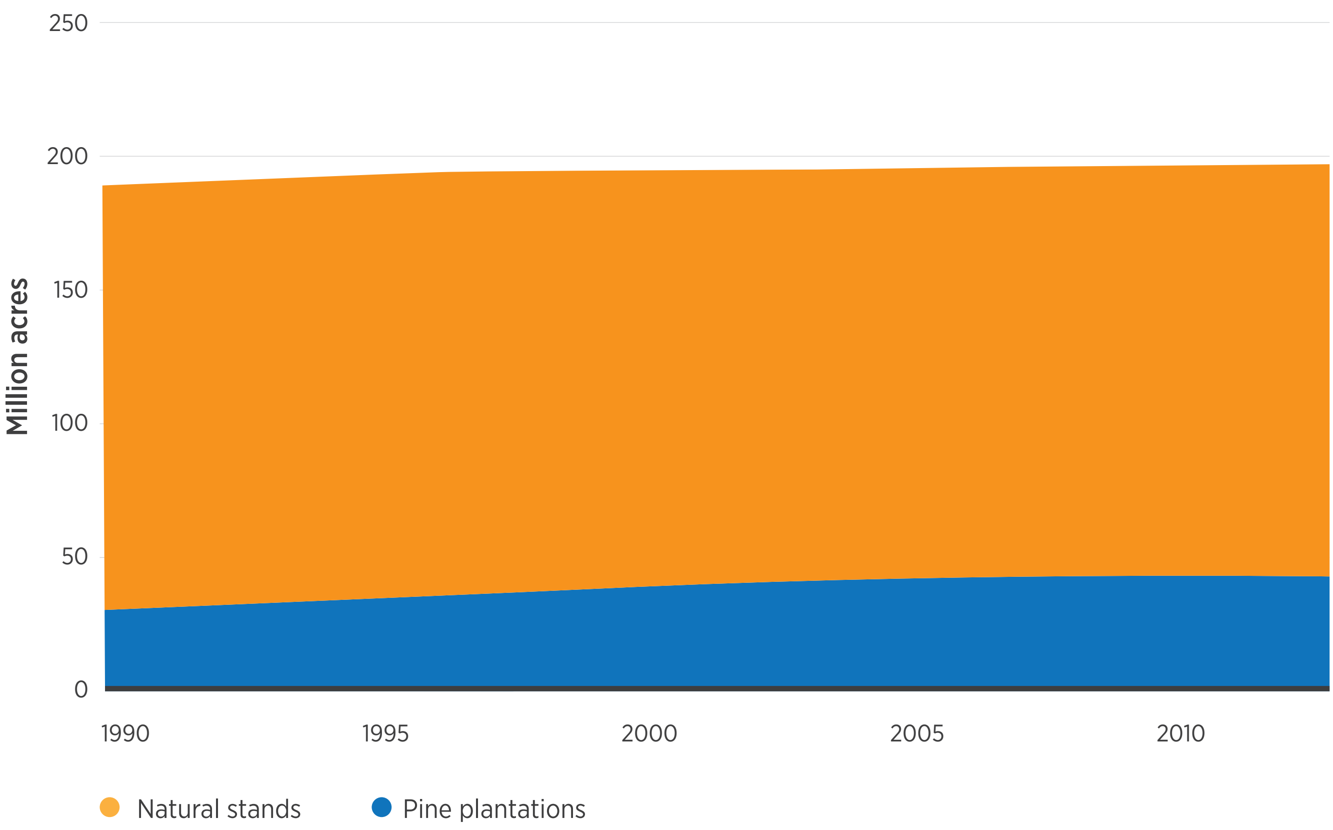
● Inventory ● Removals ● Price

Timberland Area—U.S. Coastal South

As shown earlier in figure 3.12, and in figures 3.42 and 3.43, the area of planted pine in the South increased steadily from 1990 to 2013, increasing from 16% of U.S. Coastal South forests to 22% of those forests over 24 years. This rate of planting increase, however, has slowed in recent years; it is down from 1.3% per year during 1990–2005 to only 0.5% per year in 2005–2013. During that same time period, natural forests decreased by a total of 3%; the fastest period of decline (1990–2005 at -0.13%/year) coincided with the fastest period of growth in planted pine. In more recent years (2005–2013), this rate of loss has slowed to only -0.02%/year.

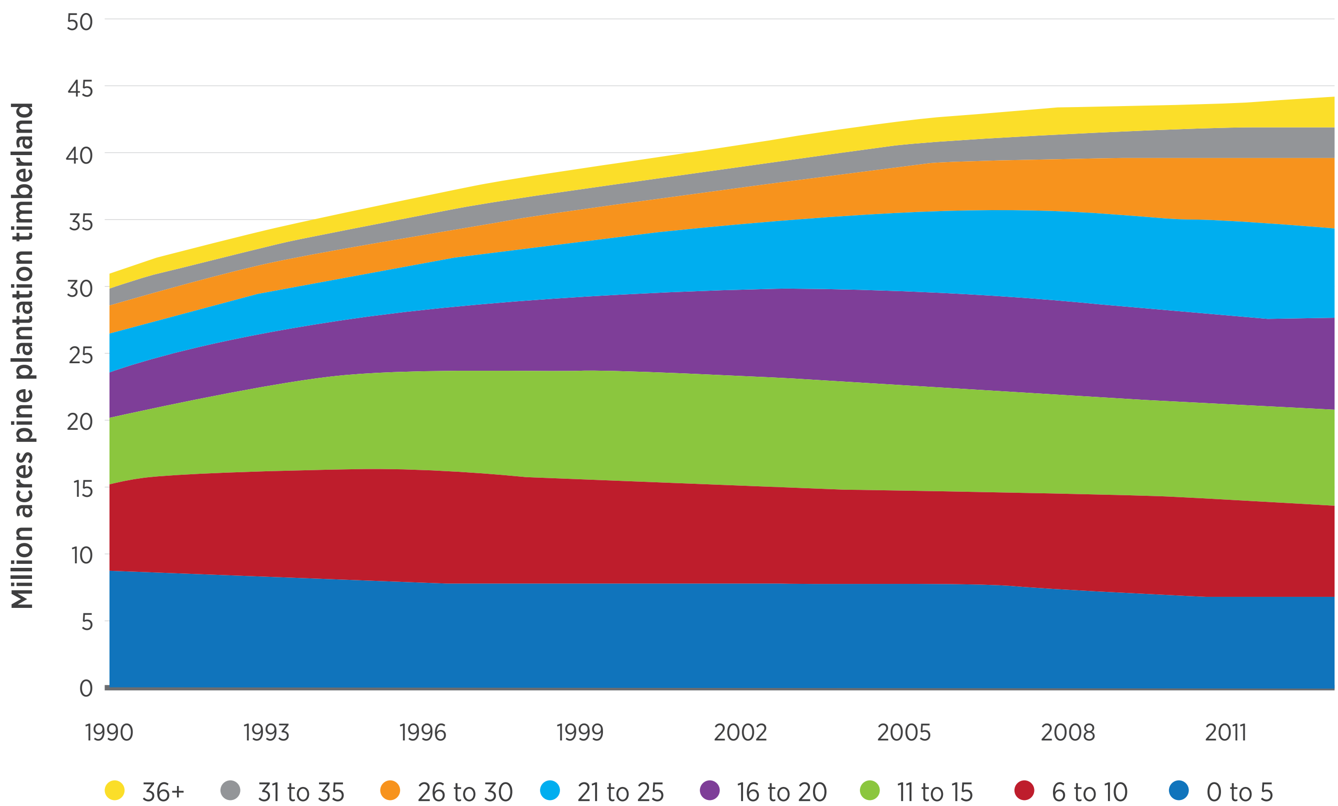
Figure 3.43 shows that the area of plantations in the youngest age class (0–5 years) has declined by the "lump" in age classes that resulted from planting subsidized by the Conservation Reserve Program. As this lump works its way through the age classes, we would expect total planted acres to decline unless additional assistance programs or increased sawtimber prices combine to increase landowner incentives to plant pine.

Figure 3.42 | Acres of natural stands and pine plantations in the Coastal South, 1990–2013



Source: Data from SOFAC (2015) and USDA Forest Service (2015a).

Figure 3.43 | Pine plantation acres in the Coastal South by age class

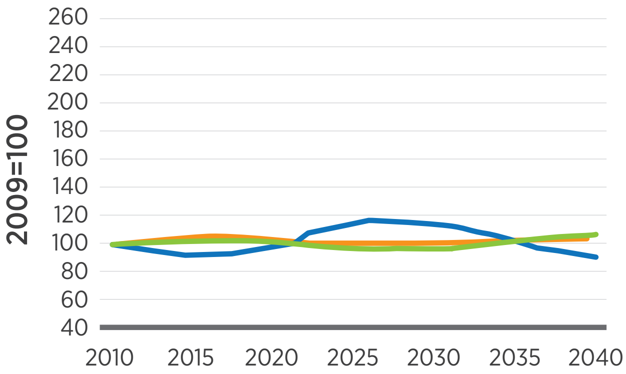


Source: Data from SOFAC (2015) and USDA Forest Service (2015a).

The projected effect of this falloff in planting can be seen in figures 3.44 and 3.45. Figure 3.44*A* and *C* show the baseline projections for softwood small and large roundwood, respectively. The projected baseline changes over time in the small roundwood market do not exceed 20% (up or down), similar to the subregional projections. The baseline changes in the softwood large roundwood market are also similar to the subregional projections, reflecting an accumulating large roundwood inventory, and corresponding low prices, even as removals rise to near pre-recession levels. Adding an increase in wood energy demands (fig. 3.44*B* and *D*) also produces projections similar to the subregional projections, with increases in small roundwood prices, especially in the middle of the projection, and then prices falling as inventory rises toward 2040. Inventory increases are a result of the projected increase in timberland acres, which is a result of the increased land rents resulting from increased softwood small roundwood prices. The addition of wood energy demands has little effect on the large roundwood markets, except that toward the end of the projection, prices fall slightly as the increases in planting lead to increased large roundwood inventories by 2040. Consistent with expectations, the changes in the projections for the Coastal South are smaller than the projections for the individual subregions.

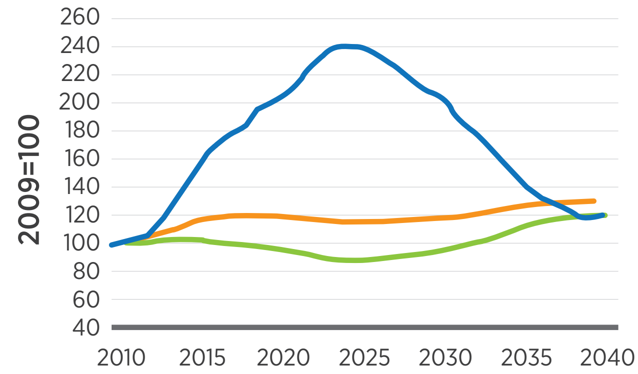
Figure 3.44 | Total Coastal South projection results showing inventory, removals, and price indices for small roundwood for 2010–2040 for both the baseline and wood energy scenarios and both pine and hardwood

A



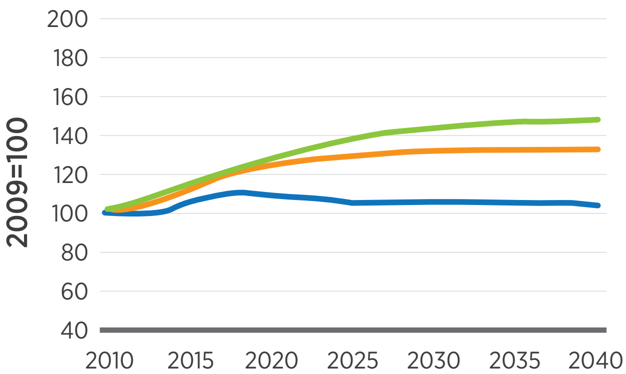
Baseline scenario: pine roundwood

B



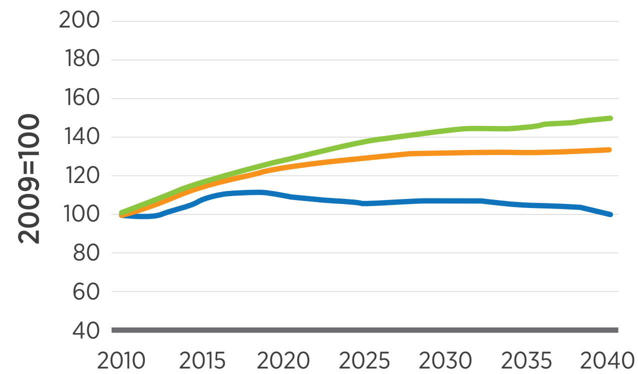
Wood energy scenario: pine small roundwood

C



Baseline scenario: softwood large roundwood

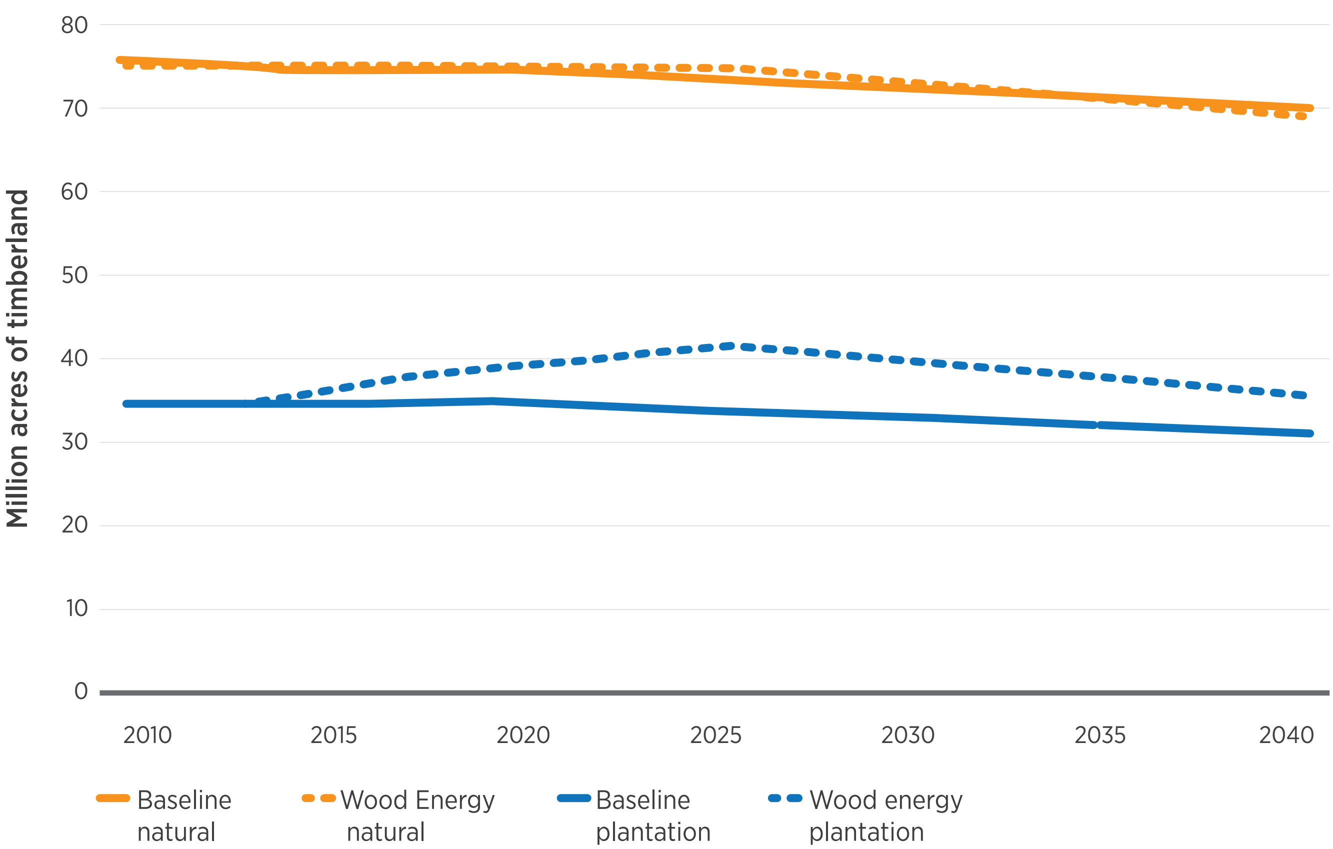
D



Wood energy scenario: softwood large roundwood

● Inventory ● Removals ● Price

Figure 3.45 | Projected land use for Coastal South, 2011 to 2040, showing assumed split between pine plantations and natural forest for both the baseline and wood energy scenarios



3.5.10 Conclusions

Timber markets in the South are affected by the age class distribution and broad management types in the current forest, and these markets in turn affect future age class distributions and management types. Because both small- and large-diameter roundwood can be produced from a single acre of timberland (although they not always are), the product markets for large- and small-diameter timber are linked at each point in time. In addition, because the only way to get large-diameter timber stands is to allow small-diameter stands to age, markets are also linked over time.

Competition for pine small roundwood in some regions is likely to intensify with increased demands for wood biomass feedstocks, leading to higher prices and some potential reductions in other uses, as shown in the Mid-Atlantic subregion. Past reductions in conventional demands for hardwood small roundwood imply that prices for this feedstock are not likely to increase as rapidly as prices for pine small roundwood.

An increase in demand for small-diameter roundwood alone, however, is not likely to affect the demand for sawtimber. And as shown for the Gulf Coast subregion earlier, using projected demands, the prices for sawtimber will likely continue to stay low; this may reduce landowner incentives to replant, as well as the availability of land for replanting. This final harvest, which occurs for sawtimber production and provides planting opportunities, will affect the availability of “thinnable” acres in the 10–15 years following the harvest and thus affect the availability of the next generation of small-diameter softwood removals.

Potential recovery in the housing and lumber markets leading to renewed sawmilling has the potential to increase the availability of sawmill residues, which may ease the pressure on the small roundwood resources and thus ameliorate price increases and impacts on other uses. As shown for the Southeast Coast region earlier, this impact is greatest in areas that have active sawmilling industries and smaller average diameter sawmill inputs.

Finally, timberland has been shown to respond to land rents, and increased demand with a quasi-fixed inventory will lead to higher prices and thus higher land rents. In this way, increased demand for feedstock for wood energy can contribute to increased timberland area (or at least to smaller decreases in timberland area).

3.6 Summary and Discussion—Forest Resources to Roadside

This chapter considers only primary forest resources (i.e., those that come directly from the forests). These are logging residues and whole-tree biomass. Three other categories of forest feedstocks do come directly from forestland but are considered to be waste for the purpose of this report. They are described and quantified in chapter 5.

An economic model, ForSEAM, is used to develop supply curves for biomass from the land. The model simulates the annual harvest of commercial products as a way to estimate logging residues. These products include sawtimber, pulpwood, and roundwood for board products. In addition, the model provides estimates of whole-tree biomass harvested for biomass uses only. Logging residues are trees not meeting merchantable timber specifications and tree components, such as limbs, tops, and cull logs. Whole-tree biomass is a combination of merchantable trees and trees not meeting merchantable timber specifications. The whole-tree biomass comes from stand diameter classes without larger, merchantable sawtimber trees. The simulation uses two types of harvesting (cutting) options: clear cutting and thinning.

Only timberland is used in the model, rather than all forestland. Both private and federal timberlands are included, but there are restrictions on slope and reserved land.

Other parameters considered and included in the model are (1) wood type, (2) stand type, (3) land slope, (4) product types, (5) regions, (6) costs, and (7) time (year). All the outputs of the model by county will be made available in the Bioenergy KDF. For example, estimates of biomass availability by ton are developed as logging residues from clear cutting and thinning operations and as whole-tree biomass harvested from clear cutting and thinning operations to meet extra biomass demands as allocated down to a county. Appendix B discusses FIA estimates and sampling errors for forestland area and forest biomass. Estimates are aggregated into national estimates as reported, and the disaggregated estimates are in the Bioenergy KDF. Wood waste resource analyses are moved to chapter 5. Federal lands are included from the forest resource analysis—the model uses private industrial, private non-industrial, and federal timberlands.

Input costs are developed explicitly for the model. These costs are used for relative seeding of the model to account for different stumpage prices that indicate product value and to account for relative differences among harvesting systems, such as machinery types and the makeup of systems specific to stand, tree size, wood type, and land slope. Other differences include regional labor rates and whether the product is timber (roundwood in the model) or biomass (whole-tree chips in the model).

Cost curves are developed for the logging residues and the whole-tree biomass within the demands of six selected scenarios of wood use and possible increases in the use of wood for energy. The projections for U.S. forests and forest products markets are under varying market conditions. USFPM/GFPM and the SRTS inventory and harvest model for the South are used to project the harvest removals, inventory, price, and timberland area resulting from three levels of wood biomass feedstock demands. The scenarios range from a baseline to high wood/biomass demand scenarios: Baseline_ML, MM, MH, HL, HM, and HH.

Although a more in-depth analysis of the sustainability of forest resources from the land will be forthcoming, an effort is made to use assumptions and methods that provide some basis for sustainability in this report. A few of the cautions and constraints involved the following:

- Restricting harvest to timberland within private ownership, which excludes designated reserved land or protected areas
- Restricting the removal of logging residues to slopes less than 40%
- Assuming BMPs are used to harvest and assuming costs for such practices in the estimates.

Using these demands, ForSEAM is used to develop supply curves (appendix B) for which cumulative supply estimates in dry tons are developed as a function of marginal costs per ton for stumpage and harvest cost to the landing (i.e., roadside cost per ton). Summaries of aggregated forest biomass available for the analysis period and under selected parameters are shown in table 3.26.

A summary of forest resources to the roadside at a price of $60 per dry ton is shown in table 3.27 for the baseline and the representative high scenario. These are the selected forest resource availabilities used in the summary and total biomass of *BT16* in the executive summary, table ES.1. Although the HH scenario is used as the representative high-biomass scenario, some of the other scenarios actually produce more biomass (see all the scenarios in table 3.20). The decision was made to use the HH scenario as the high biomass scenario to remain consistent with the RPA 2010 assessment (USDA Forest Service 2012a) and the USFPM, GFPM, and SRTS Models used in the analysis. The decision not to establish biomass plantations in this study does not negate that the HH is the highest biomass scenario. The plantation restriction needs additional consideration and further analysis to evaluate the merits and concerns of establishing millions of acres of fast-growing energy plantations on forestland. As mentioned, such woody crops are considered to be a significant feedstock on agricultural land, as reported in chapter 4.

Another result in some cases is that the available biomass in the out years from the 2015 baseline decreases. The decrease is the result of the model restriction concerning the harvest of whole trees from the small-diameter stands. If stand diameter class 3 stands are allowed to be harvested every 7 years (i.e., the time to grow large enough to become a stand diameter class 3), then more biomass is available in the out-years. However, this would exclude any late seral or mature forest stands from the successional development of the small-diameter stands. To overcome the issue of maintaining much of the forest cover in repeating small-diameter stand development, stands are harvested only once for biomass (i.e., whole-tree biomass stands) and then put back into longer-term timber rotations. Since doing so takes considerable time, much longer than the 25-year modeling time span, it reduces the amount of biomass available for harvest toward the end of the modeling period. The model still maintains that state-level growth must always exceed harvest levels, and this longer outlook helps to ensure sufficient growth, as well as diverse, multiple-aged stands across the landscape.

Table 3.26 | Summary of Baseline and High Forest Resources by Cost, Year, and Feedstock Type

Stand species	$40				$60				$80			
	2017	2022	2030	2040	2017	2022	2030	2040	2017	2022	2030	2040
	Million dry tons											
Baseline_ML[a] (Baseline scenario)[b]												
All land												
Logging residues	17.9	19.4	21.4	20.8	17.9	19.4	21.4	20.7	17.9	19.4	21.4	20.8
Whole-tree biomass	3.1	1.0	0.3	0.0	69.9	73.7	59.8	60.7	98.1	96.6	94.6	95.2
Federal land excluded												
Logging residues	15.7	17.1	18.8	18.4	15.7	17.1	18.8	18.4	15.7	17.1	18.8	18.4
Whole-tree biomass	2.8	1.0	0.3	0.0	52.3	55.4	42.7	46.1	76.4	75.1	72.4	73.4
Total: Baseline (all land)	**21.0**	**20.5**	**21.7**	**20.8**	**87.8**	**93.1**	**81.1**	**81.5**	**116.0**	**116.0**	**116.0**	**116.0**
Total: Baseline (no federal)	**18.6**	**18.1**	**19.1**	**18.4**	**68.1**	**72.5**	**61.6**	**64.5**	**92.1**	**92.2**	**91.2**	**91.8**
HH[c] (High-yield scenario)												
All land												
Logging residues	18.0	19.3	20.7	19.9	18.0	19.3	20.7	19.8	18.0	19.3	20.7	19.9
Whole-tree biomass	2.7	0.7	0.1	0.0	61.3	63.7	51.0	40.7	65.0	63.7	62.3	63.1
Federal land excluded												
Logging residues	15.7	16.9	18.1	17.5	15.7	16.9	18.1	17.5	15.7	16.9	18.1	17.5
Whole-tree biomass	2.5	0.7	0.1	0.0	46.1	48.4	37.3	33.2	48.6	48.4	46.5	51.0
Total: High scenario (all land)	**20.6**	**20.0**	**20.8**	**19.9**	**79.3**	**83.0**	**71.7**	**60.6**	**83.0**	**83.0**	**83.0**	**83.0**
Total: High scenario (no federal)	**18.3**	**17.6**	**18.2**	**17.5**	**61.9**	**65.3**	**55.4**	**50.8**	**64.4**	**65.3**	**64.6**	**68.5**

[a]The baseline is “moderate low”: moderate growth in housing starts, plantation intensity, paper, and foreign demand and low growth in biomass for energy.

[b]Baseline_ML is comparable to the base-case scenario in chapter 4.

[c]The HH scenario is “high high” scenario: high growth in housing starts and planation intensity, moderate growth in paper and foreign demand, and high growth in biomass for energy. HH does not produce the most biomass because there was no conversion of natural stands to plantations in the model. HH is comparable to the high-yield scenario for agriculture at 3% in chapter 4.

The underlying assumptions are very important with regard to the available forest biomass. In each of the six scenarios, the amount of wood available for harvest to meet traditional and biomass demands is limited by three factors. The first factor is the growth constraint at the state level, which limits harvest to the estimated annual growth. The second factor limits the amount of harvest that could occur in any single POLYSYS region (modeling unit) to 5% of the available volume. This is to ensure that the model produces a patchwork of harvested sites across the landscape indicative of current timber harvests. The final constraint limits the re-harvest of land-once-harvested. Land-once-harvested in the model could not be harvested again until the land re-establishes a stand that has grown to a class 2 diameter size (i.e., a pulpwood-sized stand). As an example of the significance of the underlying assumptions, a sensitivity analysis is completed on two factors. In the first simulation, 5% of the available volume is allowed to increase to 10% (Increased Volume Scenario) in any one POLYSYS region. A second constraint change is to the re-establish stand rule to allow 1/4 of the harvested land to become available for harvest again once the stand grows to a stand class 3 diameter (Increased Volume Plus Scenario). The remainder of the stands are not harvested until the stands become at least a stand diameter class 2.

A comparison quantity of biomass available at $40, $60, and $80/dry ton in the Baseline_ML and HH scenarios with and without these changes is presented in appendix table B.8. Biomass availability expands (more tons are estimated available) as these constraints are eased. The sensitivity analysis shows that changing these assumptions (underlying assumptions) increases the amount of the biomass estimate at the $80/ton price from 83 million tons in the HH Scenario to 135 million tons in the Increased Volume Scenario. This occurs at the $60 price as well as the $40 price point.

Since the expectation is that the South will become the primary source of wood for biomass, additional analyses are completed to understand the shaping markets and changing supply. A continuing hypothesis is that conventional timber and biomass will be produced together. Associated with that assumption is that using biomass will provide management options that can lead to higher-value products and, finally, that all wood products will go to the highest value as long as markets are available. Markets for large- and small-diameter timber are linked at each point in time.

Competition for pine small roundwood in some regions is likely to intensify with increased demands for wood biomass feedstocks, leading to higher prices and some potential reductions in other uses. However, timberland has been shown to respond to land rents, and increased demand will lead to higher prices and thus higher land rents. In this way, an increased demand for feedstock for wood energy can contribute to increased timberland area (or, at least, to smaller decreases in timberland area) for all market demands.

Table 3.27 | Summary of Baseline and High Forest Resources by Cost, Year, and Feedstock Type

Feedstock	$40				$60				$80			
	2017	2022	2030	2040	2017	2022	2030	2040	2017	2022	2030	2040
	Million dry tons											
Baseline_ML[a] (Baseline scenario)[b]												
Logging residues	17.9	19.4	21.4	20.8	17.9	19.4	21.4	20.7	17.9	19.4	21.4	20.8
Whole-tree biomass	3.1	1.0	0.3	0.0	69.9	73.7	59.8	60.7	98.1	96.6	94.6	95.2
Total: Baseline	**21.0**	**20.5**	**21.7**	**20.8**	**87.8**	**93.1**	**81.1**	**81.5**	**116.0**	**116.0**	**116.0**	**116.0**
HH[c] (High-yield scenario)												
Logging residues	18.0	19.3	20.7	19.9	18.0	19.3	20.7	19.8	18.0	19.3	20.7	19.9
Whole-tree biomass	2.7	0.7	0.1	0.0	61.3	63.7	51.0	40.7	65.0	63.7	62.3	63.1
Total: High scenario	**20.6**	**20.0**	**20.8**	**19.9**	**79.3**	**83.0**	**71.7**	**60.6**	**83.0**	**83.0**	**83.0**	**83.0**

[a]The baseline is "moderate low": Moderate growth in housing starts, plantation intensity, paper, and foreign demand and low growth in biomass for energy.

[b]Baseline_ML is comparable to the base-case scenario in chapter 4.

[c]The HH scenario is "high high" scenario: high growth in housing starts and planation intensity, moderate growth in paper and foreign demand, and high growth in biomass for energy. HH does not produce the most biomass because there was no conversion of natural stands to plantations in the model. HH is comparable to the high-yield scenario for agriculture at 3% in chapter 4.

3.7 Discussion and Research Needs

The forest resource estimates presented in this report are only as good as the underlying data, and therefore are subject to assumptions in the use of the analytical tools. The forest biomass potential is assessed through an analytical process with estimates that are bounded by variables and assumptions. However, the authors have made every effort to reach the highest quality of data and to provide data sources, describe the models, and explain the assumptions. These data should be used and assessed along with FIA inventory data and the newest RPA report and its associated scenario assessment. Supplemental information in the Bioenergy KDF can further inform readers and help them use results of this report.

This analysis identifies several factors that merit additional discussion and development. These include a reevaluation of the underlying assumptions, technology improvement, and harvesting costs. For example, should plantations on forest sites be evaluated in the model and not just timberland? Technology improvement options could also be evaluated that were not considered in this analysis, such as increased growth rates or higher-production, lower-cost systems. Additionally, harvesting costs need to be updated and improved, as more experience in biomass harvest has occurred in the last few years. Readers are encouraged to continue to verify the analysis in this report, and to expand and improve upon it.

3.8 References

SOFAC (Southern Forest Resource Assessment Consortium. 2015. *Historical Survey Unit Data, derived from USDA Forest Service*. http://research.cnr.ncsu.edu/sofac/.

Abt, K. L. et al. 2014. *Effect of Policies on Pellet Production and Forests in the U.S. South: A Technical Document Supporting the Forest Service Update of the 2010 RPA Assessment*. Asheville, NC: U.S. Department of Agriculture Forest Service. http://www.theusipa.org/Documents/US_Forest_Service_Report_2015.pdf.

Abt, R., F. W. Cubbage, and K. L. Abt. 2009. "Projecting southern timber supply for multiple products by subregion." *Forest Products Journal* 59 (7/8): 7.

Anderson, C. J. and G. Lockaby. 2011. "The effectiveness of forestry best management practices for sediment control in the southeastern United States: A literature review." *Southern Journal of Applied Forestry* 35 (4): 170–177.

Baker, S. et al. 2013. *Regional Cost Analysis and Indices for Conventional Timber Harvesting Operations - Final Report to the Wood Supply Research Institute*. Wood Supply Research Institute and the University of Georgia Center for Forest Business. http://wsri.org/resources/media/RegCostAnalFinalRpt.pdf.

Barrett, Tara M., Glenn A. Christensen, tech. eds. 2011. *Forests of southeast and south-central Alaska, 2004–2008: five-year forest inventory and analysis report*. Gen. Tech. Rep. PNW-GTR-835. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 156 p.

Bentley, J. W., and J. A. Cooper. 2015. *Southern pulpwood production*, 2012. Edited by Southern Research Station. Asheville, NC: U.S. Department of Agriculture Forest Service.

Bentley, J. W., and C. D. Steppleton. 2012. *Southern pulpwood production*, 2010. Southern Research Station, Asheville, NC: U.S. Department of Agriculture Forest Service.

Bentley, J. W., and C. D. Steppleton. 2013. *Southern pulpwood production*, 2011. Southern Research Station: U.S. Department of Agriculture Forest Service.

BLM (U.S. Department of the Interior, Bureau of Land Management). 2014. *Public Land Statistics 2014*. Volume 199. BLM/OC/ST-15/005+1165 P-108-4. http://www.blm.gov/public_land_statistics/pls14/pls2014.pdf.

Bredhoeft, G., and M. Bowman. 2014. *State renewable energy requirements and goals: update through 2013*. http://www.eia.gov/forecasts/aeo/index.cfm.

Bureau of Labor Statistics. 2015a. *Producer Price Index*. United States Department of Labor.

———. 2015b. *State and County Wages, Quarterly Census of Employment and Wages for NAICS 1133, Logging*. United States Department of Labor.

Census Bureau. *USA Trade*. U.S. Department of Commerce. Online database. https://usatrade.census.gov/.

European Commission. 2014a. *Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: A Policy Framework for Climate and Energy in the Period from 2020 to 2030*. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2014:0015:FIN:EN:PDF.

———. 2014b. “Questions and answers on 2030 framework on climate and energy.” European Commission Press Release Database. http://europa.eu/rapid/press-release_MEMO-14-40_en.htm.

———. 2014c. *Staff Working Document on the State of Play on the Sustainability of Solid and Gaseous Biomass Used for Electricity, Heating and Cooling in the EU*. http://ec.europa.eu/energy/sites/ener/files/2014_biomass_state_of_play_.pdf.

Coops, Nicholas, C., Richard H. Waring, Michael A. Wulder, and Joanne C. White. 2009. “Prediction and assessment of bark bettle-induced mortality of lodgepole pine using estimates of stand vigor derived from remotely sensed data.” *Remote Sensing of the Environment* 113: 1058–66. http://people.forestry.oregonstate.edu/richard-waring/sites/people.forestry.oregonstate.edu.richard-waring/files/publications/Coops_2009_RSE_113.pdf.

Cristan, R. et al. 2016. “Effectiveness of forestry best management practices in the United States: Literature review.” *Forest Ecology and Management* 360: 133–151. doi:10.1016/j.foreco.2015.10.025.

De La Torre Ugarte, D. G., and D. Ray. 2000. “Biomass and bioenergy applications of the POLYSYS modeling framework.” *Biomass & Bioenergy* 18 (4): 291–308. doi: 10.1016/S0961-9534(99)00095-1.

DOE (U.S. Department of Energy). 2011. *U.S. Billion-Ton Update: Biomass Supply for a Bionergy and Bioproducts Industry*. Oak Ridge, TN. http://www1.eere.energy.gov/bioenergy/pdfs/billion_ton_update.pdf.

Domke, G. M. et al. 2013. “Estimation of merchantable bole volume and biomass above sawlog top in the National Forest Inventory of the United States.” *Journal of Forestry* 111 (6): 383–387.

Dykstra, D., B. Hartsough, and B. Stokes. 2009. “Updating FRCS, the Fuel Reduction Cost Simulator for national biomass assessments.” In *Proceedings of Environmentally Sound Forest Operations, 32nd Annual Meeting of the Council on Forest Engineering*. http://www.fs.fed.us/pnw/pubs/journals/pnw_2009_dykstra001.pdf.

Edwards, K. W., and K. W. J. Willard. 2010. “Efficiencies of forestry best management practices for reducing sediment and nutrient losses in the Eastern United States.” *Journal of Forestry* 108 (5): 245–249.

EIA (U.S. Energy Information Administration). *Annual Energy Outlook 2013*. U.S. Department of Energy. http://www.eia.gov/forecasts/aeo/pdf/0383(2013).pdf.

FAZ (Frankfurther Allgemeine Zeitung). *Changes in Forest Area Worldwide by Region from 1990 to 2010*. Statista - The Statistics Portal. http://www.statista.com/statistics/272001/changes-in-forest-area-worldwide-since-1990/.

FIA (Forest Inventory and Analysis). 2012 “2012 RPA Resource Tables.” U.S. Department of Agriculture Forest Service. http://www.fia.fs.fed.us/program-features/rpa/index.php.

Fight, R. D., B. R. Hartsough, and P. Noordijk. 2006. *Users Guide for FRCS: Fuel Reduction Cost Simulator Software*. Gen. Tech. Rep. PNW-GTR-668, Pacific Northwest Research Station, Forest Service, U.S. Department of Agriculture, Portland, OR.

Forisk Consulting. 2014. “Wood Bioenergy US (Spreadsheet data).” *Wood Bioenergy US* 6 (3).

Forisk Consulting. 2015. “Wood Bioenergy US (Spreadsheet data).” *Wood Bioenergy US* 7 (1).

Fox, T. R., E. J. Jokela, and H. L. Allen. 2007. "The Development of Pine Plantation Silviculture in the Southern United States." *Journal of Forestry* 105 (7): 337–47.

Gan, J., and C. T. Smith. 2006. "Availability of logging residues and potential for electricity production and carbon displacement in the USA." *Biomass & Bioenergy* 30 (12): 1011–20. doi: 10.1016/j.biombioe.2005.12.013

Hardie, I. et al. 2000. "Responsiveness of rural and urban land uses to land rent determinants in the U.S. South." *Land Economics* 76 (4): 659–73.

He, L. et al. 2014. "Woody biomass potential for energy feedstock in United States." *Journal of Forest Economics* 20 (2): 174–191.

Heath, L. S. et al. 2008. *2009 Investigation into Calculating Tree Biomass and Carbon in the FIADB Using a Biomass Expansion Factor Approach*. Paper read at Forest Inventory and Analysis (FIA) Symposium 2008, October 21–23, in Park City, UT.

Howard, J. L., E. Quevedo, and A. D. Kramp. 2009. *Use of Indexing to Update U.S. Annual Timber Harvest by State*. Forest Products Laboratory. http://www.fpl.fs.fed.us/documnts/fplrp/fpl_rp653.pdf.

Ince, P. J. et al. 2011a. *U.S. forest products module: a technical document supporting the Forest Service 2010 RPA assessment*. Edited by F. S.-F. P. Laboratory. Madison, WI: U.S. Department of Agriculture.

———. 2011b. "Modeling future U.S. forest sector market and trade impacts of expansion in wood energy consumption." *Journal of Forest Economics* 17 (2): 142–56. doi: 10.1016/j.jfe.2011.02.007.

Ince, P. J., and P. Nepal. 2012. *Effects on U.S. timber outlook of recent economic recession, collapse in housing construction, and wood energy trends*. Madison, WI. http://www.researchgate.net/publication/259284481_Effects_on_U.S._Timber_Outlook_of_Recent_Economic_Recession_Collapse_in_Housing_Construction_and_Wood_Energy_Trends.

Jernigan, P. et al. 2013. "Implementing residue chippers on harvesting operations in the southeastern US for biomass recovery." *International Journal of Forest Engineering* 24 (2): 129–36.

Johnson, L., B. Lippke, and E. Oneil. 2012. "Modeling Biomass Collection and Woods Processing Life-Cycle Analysis." *Forest Products Journal* 62 (4): 258–272.

Johnson, T. G., and C. D. Steppleton. 2011. Southern pulpwood production, 2009. Southern Research Station-Asheville, N.C.: U.S. Department of Agriculture Forest Service.

Johnson, T. G., C. D. Steppleton, and J. W. Bentley. 2009. *Southern pulpwood production, 2007*. Southern Research Station, Asheville, N.C.: U.S. Department of Agriculture Forest Service.

———. 2010. *Southern pulpwood production, 2008*. Edited by Southern Research Station. Asheville, N.C.: U.S. Department of Agriculture Forest Service.

Johnson, T. G., C. D. Steppleton, and M. Howell. 2008. *Trends in Southern pulpwood production, 1953-2006*. Edited by F. Service. Southern Research Station, Asheville, N.C.: United States Department of Agriculture.

Jokela, E. J., T. A. Martin, and J. G. Vogel. 2010. "Twenty-Five Years of Intensive Forest Management with Southern Pines: Important Lessons Learned." *Journal of Forestry* 108 (7): 338–347.

Kantavichai, R., T. V. Gallagher, and L. D. Teeter. 2014. "Assessing the economic feasibility of short rotation loblolly biomass plantations." *Forest Policy and Economics* 38: 126–31. doi: 10.1016/j.forpol.2013.05.003.

Kittler, B. et al. 2012. *Pathways to Sustainability-An Evaluation of Forestry Programs to Meet European Biomass Supply Chain Requirements*. New York. http://www.edf.org/sites/default/files/pathwaysToSustainability.pdf.

Lubowski, R., A. Plantinga, and R. Stavins. 2008. "What Drives Land-Use Change in the United States? A National Analysis of Landowner Decisions." *Land Economics* 84 (4): 529–50.

Mater, C. 2015. *Maximized Woody Biomass Working Circles in the US: Identification of Core and Super Core Counties. Woody Biomass Maximization Project. Mater Engineering*. Shell International Exploration and Production Inc, Corvallis, OR.

Munsell, J. F., and T. R. Fox. 2010. "An analysis of the feasibility for increasing woody biomass production from pine plantations in the southern United States." *Biomass Bioenergy* 34 (12): 1631–42.

Neff, J. 2012. "As more marketers go green, fewer consumers willing to pay for it." *Advertising Age* 83 (34): 6.

Nepal, P. et al. 2012. *Developing Inventory Projection Models Using Empirical Net Forest Growth and Growing-Stock Density Relationships Across U.S. Regions and Species Groups*. Forest Products Laboratory, Madison, WI. http://www.fpl.fs.fed.us/documnts/fplrp/fpl_rp668.pdf.

NIFC (National Interagency Fire Center). 2016. "Total Wildland Fires and Acres (1960–2015)." http://www.nifc.gov/fireInfo/fireInfo_stats_totalFires.html.

Oneil, E. E. et al. 2010. "Life-cycle impacts of Inland Northwest and Northeast/North Central forest resources." *Wood Fiber Sci*. 42 (CORRIM Special Issue): 144–64.

Oswalt, S. N. et al. 2014. *Forest Resources of the United States, 2012: a technical document supporting the Forest Service update of the 2010 RPA Assessment*. General Technical Report. U.S. Department of Energy Forest Service, Washington Office. http://www.srs.fs.usda.gov/pubs/gtr/gtr_wo091.pdf.

Penn State. 2016. "Youth: Forest Management Techniques." Penn State College of Agricultural Sciences. http://ecosystems.psu.edu/youth/sftrc/lesson-plans/forestry/9-12/forest-management.

Perez-Verdin, G. et al. 2009. "Woody biomass availability for bioethanol conversion in Mississippi." *Biomass & Bioenergy* 33 (3): 492–503. doi: 10.1016/j.biombioe.2008.08.021.

Perlack, R. D. et al. 2005. *Biomass as feedstock for a bioenergy and bioproducts industry: the technical feasibility of a billion-ton annual supply*. Oak Ridge, TN: Oak Ridge National Laboratory.

Phillips, M. J., and C. R. Blinn. 2004. "Best management practices compliance monitoring approaches for forestry in the eastern United States." *Water, Air and Soil Pollution: Focus* 4 (1):263–274.

PNW (Pacific Northwest Research Station). 2011. *Forests of Southeast and South-Central Alaska 2004–2008: Five-Year Forest Inventory and Analysis Report*. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. PNW-GTR-835. http://www.fs.fed.us/pnw/rma/fia-topics/publications/documents/AK_pnw_gtr835.pdf.

Prestemon, J. P., D. N. Wear, and M. O. Foster. 2015. *The global position of the U S forest products industry*. Asheville, NC.

Probert, T. 2012. "Biomass Industry Outlook 2013: Dogged by Regulatory Uncertainty." Renewable Energy World. http://www.renewableenergyworld.com/articles/2012/12/biomass-industry-outlook-2013-dogged-by-regulatory-uncertainty.html.

RISI. 2008. *International Wood Fiber Report*. San Francisco, CA.

Simangunsong, B., and J. Buongiorno. 2001. "International Demand Equations for Forest Products: A Comparison of Methods." *Scandinavian Journal of Forest Research* 16 (2): 155–172. doi: 10.1080/028275801300088242.

Skog, K. E. 2015. Email communication.

Smith, B. W., tech. coordinator, et al. 2009. *Forest Resources of the United States*, 2007. Washington, D.C.

Stephenson, A. L., and D. MacKay. 2014. *Life cycle impacts of biomass electricity in 2020*. UK Department of Energy and Climate Change. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/349024/BEAC_Report_290814.pdf.

Tarr, J. M., and S. Adair. 2014. *Policy Brief: The EPA's Proposed Guidelines for Regulating Carbon Dioxide Emissions from Existing Power Plants*. NI PB 13-01, Durham, NC. https://nicholasinstitute.duke.edu/sites/default/files/publications/ni_pb_14-01_0.pdf.

Turhollow, A. et al. 2014. "The updated billion-ton resource assessment." *Biomass and Bioenergy* 70: 15.

Turn, Scott Q., Vheissu Keffer, and Milton Staackmann. 2002. *Biomass and Bioenergy Resource Assessment: State of Hawaii. Hawaii Natural Energy Institute, School of Ocean and Earth Sciences and Technology, University of Hawaii*. Report prepared for the State of Hawaii, Department of Business, Economic Development and Tourism. http://pacificbiomass.org/documents/HawaiiBiomassAssessment.pdf.

UK DECC (United Kingdom Department of Energy and Climate Change). 2014. *Guidance: Timber Standard for Heat and Electricity Office for Renewable Energy Deployment*. London: Crown.

USDA-ERS (U.S. Department of Agriculture, Economic Research Service). 2015. *USDA Feed Grains Database. USDA Economic Research Service*. http://www.ers.usda.gov/data-products/feed-grains-database/feed-grains-custom-query.aspx#ResultsPanel.

USDA Forest Service. 2007. *Forest resources of the United States*. Gen. Tech. Rep. WO-78, U.S. Department of Agriculture, Washington, D.C.

———. 2012. Future of America's Forest and Rangelands: Forest Service 2010 Resources Planning Act Assessment. Washington, D.C.

———. 2015a. *Timber Product Output (TPO) Reports: National RPA Report for 2012*. U.S. Department of Agriculture Forest Service, Southern Research Station, Knoxville, TN. http://srsfia2.fs.fed.us/php/tpo_2009/tpo_rpa_int1.php.

———. 2015b. *Forest inventory and analysis, FIA data and tools*. [Online database]. U.S. Department of Agriculture. http://fia.fs.fed.us/tools-data/default.asp.

———. 2016. “Web-Based Forest Management Guides: Harvesting Systems.” http://www.nrs.fs.fed.us/fmg/nfmg/fm101/silv/p3_harvest.html.

Wang, J., D. Hartley, and W. Liu. 2013. “Biomass Harvesting Systems and Analysis.” In *Wood-Based Energy in the Northern Forests*, edited by M. Jacobson and D. Ciolkosz, 101–120. New York: Springer Publishers.

Woodall, C. W. et al. 2011. *Methods and Equations for Estimating Aboveground Volume, Biomass, and Carbon for Trees in the U.S. Forest Inventory,2010*. Newtown Square, PA. http://www.treesearch.fs.fed.us/pubs/39555.

Zhou, X. et al. 2011. “The use of forest-derived specific gravity for the conversion of volume to biomass for open-grown trees on agricultural land.” *Biomass & Bioenergy* 35 (5): 1721–31. doi: 10.1016/j.biombioe.2011.01.019.

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