Chapter 10: Forest Biomass-Based Energy

Janaki R. R. Alavalapati, Pankaj Lal, Andres Susaeta, Robert C. Abt, and David N. Wear[1]

Key Findings

- *Harvesting woody biomass for use as bioenergy is forecasted to range from 170 to 336 million green tons by 2050, an increase of 54 to 113 percent over current levels.*
- *Consumption forecasts for forest biomass-based energy, which are based on Energy Information Administration projections, have a high level of uncertainty given the interplay between public policies and the supply and investment decisions of forest landowners.*
- *It is unlikely that the biomass requirement for energy would be met through harvest residues and urban wood waste alone. As consumption increases, harvested timber (especially pine pulpwood) would quickly become the preferred feedstock.*
- *The emergence of a new woody biomass based energy market would potentially lead to price increases for merchantable timber, resulting in increased returns for forest landowners.*
- *While woody biomass harvest is expected to increase with higher prices, forest inventories would not necessarily decline because of increased plantations of fast growing species, afforestation of agricultural or pasturelands, and intensive management of forest land.*

[1] Janaki R.R. Alavalapati is a Professor and Department Head of Forest Resources and Environmental Conservation, Virginia Tech, Blacksburg, VA 24061. Pankaj Lal is a PhD Candidate, School of Forest Resources and Conservation, University of Florida, Gainesville, FL 32611. Andres Susaeta is a Postdoctoral Scholar, Department of Forest Resources and Environmental Conservation, Virginia Tech, Blacksburg, VA 24061. Robert C. Abt is a Professor, Department of Forestry and Environmental Resources, North Carolina State University, Raleigh, NC 27695. David N. Wear is the Project Leader at the Forest Economics and Policy Research Work Unit, Southern Research Station, U.S. Department of Agriculture, Forest Service, Research Triangle Park, NC 27709.

- *Because it would allow more output per acre of forest land and dampen potential price increases, forest productivity is a key variable in market futures.*
- *The impacts that increased use of woody biomass for energy would have on the forest products industry could be mitigated by improved productivity through forest management and/or by increased output from currently unmanaged forests.*
- *Price volatility associated with increased use of woody biomass for energy is expected to be higher for pulpwood than for sawtimber.*
- *The impacts of wood based energy markets tend to be lower for sawtimber industries, although markets for all products would be affected at the highest levels of projected demand.*
- *Different types of wood based energy conversion technologies occupy different places on the cost feasibility spectrum. Combined heat and power, co-firing for electricity, and pellet technologies are commercially viable and have good prospects in future. Biochemical and thermochemical technologies used to produce liquid fuels from woody biomass are not yet commercially viable.*
- *Current research does not suggest which woody species and what traits would likely be most successful for energy production. The future of conversion technologies is uncertain.*
- *In the absence of government support, research, pilot projects, and incentives for production and commercialization of woody bioenergy markets are unlikely to develop.*
- *Forecasted levels of woody biomass harvests could lead to a reduction of stand productivity, deterioration of biodiversity, depletion of soil fertility, and a decline in water quality.*
- *Although research provides some guidelines for the design of management to protect various forest ecosystem services, forest sustainability benchmarks for bioenergy are not well defined and existing certification systems have few relevant standards.*

Introduction

The United States is the largest consumer of petroleum products, consuming about 19.5 million barrels per day in 2008 (Energy Information Administration 2009), with a significant portion imported from politically unstable regions of the world. This reliance on imported fossil fuels, coupled with their associated greenhouse gas emissions, has led to economic, social and environmental concerns. Bioenergy may offset fossil fuel use, diversify energy sources, reduce emissions, and provide socioeconomic benefits in the form of additional income and new jobs. Bioenergy from woody biomass could contribute by increasing U.S. renewable energy resources, reducing competition between agricultural crops destined for food and those for fuel production (Hill and others 2006), and perhaps improving the condition of some forests. Some analysts, for example the Manomet Center of Conservation Sciences (2010) in their analysis of wood-based bioenergy in Massachusetts raise doubts about the green house gas mitigation potential of forest bioenergy. Others, such as Lucier (2010) and O'Laughlin (2010) challenge these findings. In the South, studies such as Dwivedi and others (2011) indicate that southern pine based energy could reduce green house gas emissions as compared to using fossil fuels.

Although historically limited to residues from the production of wood products, biomass could be sourced from logging residues, stands damaged by natural disturbances (such as wildfire, pest outbreaks, and hurricanes), small-diameter trees thinned from plantations and other forests, and energy crops such as eucalyptus and poplar; these sources would likely be tapped as woody bioenergy markets become competitive. At high enough prices, even merchantable timber could be diverted to bioenergy uses. Hughes (2000) suggests that the combination of forest bioenergy plantations and continued use of wood residues from forest product industries could supply 7 to 20 percent of the U.S. electricity generation in the future.

Many pine plantations established to supply pulpwood for paper and engineered wood products are overstocked and therefore susceptible to wildfires and pest attacks (Gan and Mayfield 2007a).For example, nearly half of over 1.1 million acres of nearly pure pine stands are at risk from southern pine beetle in Oklahoma (Oklahoma Department Of Agriculture Food And Forestry, 2008). Wood-based bioenergy markets could increase thinning and removals, thereby reducing these risks (Gan and Mayfield 2007a; Belanger and others 1993; Speight 1997; Neary and Zieroth 2007). Schmidt et al. (2002) estimated that 2.7 billion dry tons of forest biomass needs to be removed through forest fuel reduction treatments in the South, about 20 million dry tons annually. Furthermore, wood based bioenergy markets would improve profitability for landowners in the South (Susaeta and others 2009, Nesbit and others 2011). Furthermore, southerners appear willing to pay more for cleaner sources of energy such as wood based biofuels (Susaeta and others 2010).

Federal policies such as the 2002 Farm Bill, 2005 Energy Policy Act, 2007 Energy Independence Security Act, and 2008 Farm Bill have specifically encouraged the production of cellulosic biofuels such as those produced from wood, ranging from grants and loans to the establishment of renewable fuel standards (15.5 billion gallons in 2012, and 36 billion gallons by 2022 of which 21 billion gallons must be cellulosic). Federal law provides differing definitions of acceptable forest biomass for bioenergy. For example, under the 2007 Energy Independence Security Act biomass from public lands, municipal solid waste, plantations established after the enactment of the Act, old growth' or 'mature' forests, and most other woody biomass (except for slash and pre-commercial thinning) is excluded from private and non-industrial forests (NIPFs) landowners. The 2008 Farm Bill on the other hand is less restrictive as it allows for biomass derived from federal lands and other forests (i.e., not tree plantations) as biofuels. The American Clean Energy and Security Act of 2009 (H.R. 2454), as passed by the House of Representatives, sought to create a broadened universal definition of renewable biomass that applies to Renewable Fuel

Standard, and a national Renewable Electricity Standard. We followed a non-restrictive definition of biomass while simulating supply variations and Southern forests and considered that aboveground biomass on private forestlands in the South could be used for energy production. This is based on the assumption that policy would not restrict the allocation of forest biomass to bioenergy uses.

This chapter analyzes the potential effects of the emergence of a bioenergy market on southern forests, forest owners, traditional forest product industries, and ecosystem integrity and services; with emphasis on the following key issues:

- *How markets for wood for energy production might evolve and potential implications for traditional forest product industries and landowners*
- *The status of current and potential technologies that can help realize large-scale production of woody bioenergy*
- *How bioenergy policies could impact forest landowners and forest industry*
- *Effects of woody bioenergy markets on forest ecosystems health; benchmarks for sustainability*

Methods

We surveyed the literature to address questions about technology development, bioenergy policies, and sustainability, and we developed detailed modeling to forecast market changes and incorporate an analytical component into the results of the literature survey.

To assess tradeoffs between the traditional forest product industry and the woody bioenergy industry, we evaluated woody biomass supply variation through time and associated price, inventory, and removal responses following Rossi and others (2010). In the face of future competition for raw materials and the potential competitive advantage that policy incentives would provide to woody bioenergy sector, this tradeoff analysis was considered critical for the future of southern forests (Wear and others 2009). Many authors have explored this issue; what has been lacking is a systematic analysis of regional trends that assesses woody biomass supply in response to variation in future consumption for energy.

We modified the Subregional Timber Supply (SRTS) model, (Abt and others 2000) to assess the potential effects of bioenergy consumption on wood products markets. The model provided price, inventory, and removal responses for different wood-for-energy consumption and supply scenarios; and allowed us to estimate impacts on traditional forest industries and landowners.

Of the large-scale macro models available for conducting our analysis (De La Torre Ugarte and Ray 2000; De La Torre Ugarte and others 1998, 2006; Adams and others 1996), the SRTS model is the only one that treats standing timber as a potential supply of bioenergy and defines regions in a way that is congruent with Forest Inventory Analysis (FIA) survey units. Because it incorporates an inventory projection model into a timber market model framework, its projections are based on supply and demand interactions. It allows of larger diameter sawtimber to be downgraded for nonsawtimber (pulp) and is familiar to many forest industry analysts and State forestry agencies, having been used to model timber supply and prices in the Northeast (Sendek and others 2003) as well as the South (Prestemon and Abt 2002, Bingham and others 2003). It has also been used to assess the influence of nonmarket values on timber market decisions by nonindustrial private forest landowners (Pattanayak and others 2005), the effects of wood chip mills on timber supply in North Carolina (Schaberg and others 2005), the impacts of Renewable Energy Standards policy implemented in North Carolina (Galik and others 2009), and bioenergy demands in South (Abt and Abt in press).

The SRTS model estimates two forest products (sawtimber and pulpwood product allocations for softwoods and hardwoods. Its equations—defined through supply, demand, and inventory elasticity values—are used to forecast the market-clearing price and quantity levels, which in turn are used to allocate subregional harvesting and to project the next period's inventory values. A Goal Program then categorizes the total wood requirement by management type and age class and makes allocations to subregions, owners, and products.

The separation of products and inventory in terms of sawtimber and pulpwood is based on user-specified definitions that allocate most of the largest diameter wood to saw mills, a percent of the largest diameter and all of the medium diameter wood to pulpwood, and the smallest diameter wood to the forest floor. With these allocations, a product mix is calculated for harvest in any management type and age class with the objective of defining the projected removal mix for the region/owner in a way that follows historical harvest patterns of existing removal-to-inventory intensities. For partial harvests, the model defines a stocking target (volume per acre) for each management type and age class; if the current stocking is greater than the target, the harvest is considered a thinning. After the volume-per-acre target is reached, the harvest considered final and acres are returned to age class zero. Under most circumstances, this approach ensures that average stocking is close to target (historical) levels throughout the projection (Abt and others 2000; Prestemon and Abt 2002; Rossi and others 2010; Abt and others 2009, 2010; Abt and Abt 2010).

We made a number of modifications to the SRTS model (fig. 10-1) to assess the effects of woody bioenergy industry on future prices, harvests, and inventories of four wood product categories—softwood sawtimber, other softwoods, hardwood sawtimber, and other hardwoods—derived from private owners of forest land (public forest lands have been excluded from the study, because public land harvest decisions are not necessarily price-responsive). Appendix A contains descriptions of these products and the allocation of consumption of each for woody bioenergy production. The model allocates woody biomass consumption among product groups based on the price variations. Pine plantations can be harvested for pulpwood as early as 10 years of age. To determine the availability of harvest residuals, we applied utilization percentages that are consistent with timber product output data for the South (Johnson and others 2009).

Alternative runs of the model allowed us to examine how management or genetic improvements would affect productivity. Rather than applying identical responses across the five forest management types (pine plantation, natural pine, oak-pine, upland hardwood, and lowland hardwood), we modified the model so that responses can be disaggregated across them.

Within the SRTS model, the area of timberland will change in response to the relative rents of crop and forest uses. We defined timber rents as weighted averages of sawtimber and nonsawtimber prices, with weighting specified by the present value difference in income between the two products while agricultural rents are held constant. Because woody bioenergy markets are expected to impact the nonsawtimber sector more than the high valued sawtimber sector (Aulisi and others 2007), the model allocates less weight to sawtimber prices.

We used the aggregate demand information gathered from each southern wood based industry—forest products, woody biomass-based electricity, woody biomass-based liquid fuels, and wood pellets—to project the allocation of harvested timber. The modified SRTS model defines a market simulation model based on empirical relationships—demand and supply, price, land use, reforestation and inventory—for woody biomass and traditional forest products. A key assumption is that forest owners are price responsive and decisions to invest or harvest are made accordingly.

Consumption/Demand Scenarios

Our consumption scenarios were based on the three principal uses of woody biomass for energy: as power for electricity generation through combustion or gasification processes, co-firing with coal, or in combined heat and power systems in industrial facilities (Energy Information Administration 2010b); as liquid fuel (cellulosic ethanol) that can be blended with conventional transportation fuels (Energy Information Administration 2010b); and as bioproducts such as highly compact wood pellets used for heating purposes (Spelter and Toth 2009, appendix A).

The amount of wood consumed for electricity, liquid fuels, and pellets defines the total requirement for meeting bioenergy consumption forecasts. This can be met with wood from additional harvesting or with residuals and other wood waste. Although harvesting unutilized residues (discarded tree tops and limbs generated during the harvesting process) might provide a portion of woody biomass-based energy consumption, recent analysis (Galik and others 2009; Rossi and others 2010) indicates that merchantable timber is also likely to be required. In addition, woody biomass-based energy demand figures need to account for urban wood wastes that could be used for energy production (Rossi and others 2010). Because the SRTS model deals only in harvested wood, we backed urban waste and other sources of nonharvested woody biomass out of the consumption estimates, and defined the remainder as harvested-wood consumption (including harvesting residues) for woody biomass-based energy; appendix A shows the method used to estimate the harvesting residues and urban wood waste that can be diverted for energy production. Demand price elasticity, which like inventory supply elasticity can vary by product (Pattanayak et al. 2002; Liao and Zhang 2008), was assumed to be -0.5 for all four SRTS products (softwood/hardwood sawtimber and nonsawtimber), the same assumption used by Abt and Abt (2010) for their Southwide timber supply analysis.

Demand for woody biomass for energy can also be met with fast-growing short rotation woody crop species, among them yellow-poplar (*Populus* ssp.), willow (*Salix* spp.), cottonwood (*Populus fremontii* L.), sweetgum (*Liquidambar styraciflua*), sycamore (*Platanusoccidentalis*), black locust (*Robinia pseudoacacia*), silver maple (*Acer saccharinum* L.), and eucalyptus (*Eucalyptus cinerea*); these species have been identified by the U.S. Department of Energy as potentially viable for energy production. We followed the approach outlined by the Energy Information Administration (2010a) and assumed that short rotation woody crops would grow largely on nonforested lands (agricultural or pasture lands) and partially offset increased future wood requirements. We assumed of the offset to be 10 percent by 2050 and removed this material from woody biomass demands for bioenergy (in effect, treating short rotation woody crops as a part of the agricultural sector).

Although we describe our assumptions as consumption scenarios, it is important to understand that they are not demand projections, as we have not specified price-responsive demand relationships for woody biomass and traditional forest products. The consumption forecast is essentially a vertical demand curve added to the downward sloping demand curves for traditional forest products for each period using modified Energy Information Administration (2010b) projections. As a counterfactual, we also introduced a constant consumption scenario with no forest biomass-based energy market and ran the SRTS model to define the amount of woody biomass that would be required by traditional forest industry absent a bioenergy market. Subsequent years are held constant at the original 2010 level on the assumption that the traditional forest product industry will not increase wood consumption beyond what would be expected at the constant price level estimated by SRTS.

To account for uncertainty in bioenergy technologies, demands, and policies, we considered three consumption scenarios: high, medium, and low. The low-consumption scenario assumes that 7.74

percent of total electricity will derive from renewable sources based on Energy Information Administration (2010b) reference case forecasts. The medium-and high-consumption scenarios assume that 20 percent of total electricity consumption derives from renewable sources; in the high-consumption scenario, woody biomass is assigned a higher percentage of the total electricity generation from renewable sources (table 10-1).

Biomass Supply

The SRTS model accounts for forest inventory changes and timber removals based on historical forest inventory (FIA) data. However, southern forest productivity has seen a three-fold over the last 50 years from advancements in management and genetic improvements (Fox and others 2007). Siry and others (2001) forecasted that productivity gains for pine plantations could be as high as 100 percent of empirical FIA data (using data from the late 1990s) over the next 50 years. Prestemon and Abt (2002) assumed a 75-percent productivity gain in southern pine plantations from 2000 to 2040. With strong markets, other forest management types might experience productivity gains due to silvicultural improvements or improvements in management, although not as high as pine plantations.

We developed supply projections to examine alternative trajectories of productivity increases through 2050. In these projections, productivity growth is applied to every acre every year, so that over time the improved silvicultural practices on existing or new forest stands or genetic improvements of new plantations result in an aggregate growth response. For the “pine productivity” strategy, we assumed that pine plantation productivity increases steadily until it reaches 100 percent, while the productivity of other forest management types is held constant. For the “all productivity” strategy, we assumed a 100-percent pine plantation productivity increase and a 25-percent increase for other types. For the “low productivity” strategy, pine plantation productivity increases by 50 percent and the productivity of other types increases to 25 percent (tables 10-2 and 10-3). These assumptions are in line with hardwood field trials that report growth responses between 17 and 33 percent after stem density reduction, herbaceous competition control, and fertilization (Siry and others 2004).

Within SRTS, removals are treated as a function that responds to changes in the product price and the total biomass inventory. The timber supply elasticity with respect to inventory has been assumed to be 1.0 for all products and owners. For own-price elasticities of timber supplies (elasticity of product demand with respect to their own price), we used the average bootstrapped values for A1B and B2 cornerstone futures described in chapter 9, which vary across products and years and range from 0.18 to 0.32.

Results

Market Analysis

By 2050, woody biomass consumption is forecasted to range from 150.16 million green tons for the low-consumption scenario to 235.88 million for the medium-consumption scenario and 316.12 million for the high-consumption scenario (fig. 10-2). The amount of urban wood waste amounts to about 12.72 million in 2010 and trends slightly upward throughout the projection period to reach 20.08 million by 2050. In contrast, the forecast of biomass requirement for the forest products industry (held constant through the projection period) is about 278.46 million. By 2050, the biomass requirement for energy reaches about 54 percent of the forest products requirement for the low-consumption scenario and 85 percent for the medium scenario. For the high-consumption scenario, the bioenergy requirement exceeds the forest products requirement by 2045 and is 13 percent greater than the forest product requirement in 2050.

Adding urban wood waste and the forest biomass consumption requirement in 2050 would bring demand to 170 million tons for the low-consumption scenario, 256 million for the medium scenario, and 336 million for the high scenario. These estimates are comparable to other estimates in the literature if we assume that that supply of wood from the South mirrors the national harvest share--i.e., approximately 57 percent of national harvest as per Hansen et al. (2010).

Without accounting for milling residues, Milbrandt (2005) estimated that just 86 million tons of woody biomass is readily available for energy production (roughly half of the forecast for the low-consumption scenario). Walsh and others (2008) estimated that approximately 121 million tons of forest and mill residues could be supplied at a price of $100 per dry short ton, compared to estimates of 154 million tons by Kumarappan and others (2009).The Energy Information Administration (2007) estimated that approximately 414 million tons of wood from South might be required to meet Federal goal of 25 percent of renewable fuel and electricity standards. Sample (2009) suggested that this demand figure could be much higher, estimating the yearly requirement at 992 million green tons. Perlack and others (2005) estimated that 420 million green tons of wood resources could be annually made available for energy production from southern forests.

Consumption increases of this magnitude (at a minimum, a 54 percent increase in timber harvesting) could imply a structural change in forest products markets. Analysis of traditional wood products markets (ch. 9) indicates that the supply of biomass could grow by about 43 percent under current levels of productivity without increased scarcity, largely because of declining demands for wood products. With plantation productivity growth at about 50 percent by 2060, forest biomass output could expand by as much as 70 percent without substantial impacts on market scarcity.

To identify the market implications of the three consumption scenarios, we ran the SRTS model, which provides projections of the removals from growing stock resulting from timber harvesting but does not distinguish among final products. To deduce the implications of increased woody biomass requirement for the traditional wood products industry, we disaggregated the removals forecasts into harvesting residues, additional removals that could not have occurred without woody bioenergy markets, and/or displacement from traditional wood product industry.

To ensure that some slash is left on the ground, we constrained the SRTS model so that no more than 67 percent of harvesting residues could be diverted for energy production. The constant consumption scenario (with no expanded demand for bioenergy) defines a base harvest projection for the traditional wood products industry. Comparing the SRTS projections for a bioenergy consumption scenario with the base harvest for forest industry defines the additional harvesting associated with the bioenergy scenario (new removals). Comparing new removals with the bioenergy requirement (less harvest residues) provides an estimate of the timber that would be diverted from forest industry for woody biomass based energy production (displacement). Because the maximum amount of product displacement is constrained by forest product industry consumption, the possible product shortfalls that may arise due to additional biomass demands for bioenergy are met by other softwoods and hardwood product removals.

The remaining paragraphs in this section summarize forecasts that assume a base harvest for forest industry and three bioenergy consumption scenarios without in the absence of supply expansion through productivity growth.

No consumption for bioenergy—Figure 10-3 shows the results of the SRTS model run for four product types (sawtimber softwoods, other softwoods, sawtimber hardwoods, and other hardwoods), expressed in terms of index values for prices, inventory, and removals with respect to 2007 levels. Prices decline, and inventory and removals increase for all hardwoods and for sawtimber softwoods; the reverse is predicted for the other (nonsawtimber) softwoods. This is consistent with a SRTS-based analysis (Abt and Abt 2010) that plays out the implications of a protracted recession. The scenario predicts 10 percent declines in Southern private forest acreage from 2010 to 2050 (fig. 10-4), which is consistent with the maximum forecasted forest losses described in chapter 4 and with the forest product demand analysis contained in chapter 9, which predicted constant or somewhat expanding harvest levels and declining timber prices.

Low woody biomass consumption—Harvest, inventory, and removals projections for sawtimber under the low-consumption scenario are similar to the no-consumption scenario projections (fig. 10-5), although the price reductions for sawtimber are somewhat lower. Change in prices, inventory, and removals reflect an inelastic market response as price changes more than removals or inventory.

Consistent with Rossi and others (2010), demand for wood energy leads to price increases for other (nonsawtimber) softwoods beginning in about 2016, when supplies of urban wood wastes are unable to meet the extra demand of wood for energy production, and somewhat later for nonsawtimber hardwoods. The associated price increases are more than triple 2007 levels. Substantial timber is diverted away from forest industry for energy production (fig. 10-6), with 22 million green tons of softwoods and 26 million green tons of hardwoods diverted for bioenergy production by 2050. The impact of woody bioenergy markets on sawtimber is insignificant as the displacement of nonsawtimber products takes care of additional woody biomass requirements.

Under this scenario, private forest acreage declines by 3 percent from 175.39 million acres in 2010 to 170.86 million acres in 2050 (fig. 10-7), although still 8 percent higher than for the no bioenergy consumption scenario. Pine plantation acreage increases by 7 percent accompanied by declines in the other forest management types. The increase in pine plantation area is consistent with expansion in pine planting by landowners in response to increased product prices.

Medium woody biomass consumption—Compared to the low-consumption scenario, this scenario produces more dramatic price increases earlier (fig. 10-8). By 2050, prices of nonsawtimber softwoods, nearly four times higher than 2010 levels, are somewhat moderated as landowners by increase plantings and higher pine plantation acreages in response to greater demand, causing inventory to be higher than both the no-consumption and low-consumption scenarios. Nonsawtimber hardwood prices are even higher because the model assumes that landowners will not plant slow growing hardwoods in response to increased scarcity. Plantations of fast growing hardwoods (short rotation woody crops) have been treated separately as part of agriculture, and are not included in new plantation response. The pulp industry is adversely impacted as significant supply is diverted from forest industry to energy production (Figure 10-9). Forest industry demand for nonsawtimber hardwoods is completely wiped out by 2039, and 82 percent of stocking is diverted for energy production by 2050.

Price declines for sawtimber are lower, resulting in higher price levels in the later years of this scenario compared to the no-consumption scenario. The inventory and removals also respond to the price increase, as higher prices and inventory levels translate to increases in removals. The sawtimber industry faces significantly lower impact as most of the bioenergy demands are met by displacement and new removals of other hardwoods and softwoods.

Under this scenario, the private forest acreage increases by 3 percent from 175.39 million acres in 2010 to 181.41 million acres in 2050 (fig. 10-10), 14 percent higher than the no-consumption scenario, largely caused by increases in pine plantation acreage (19 percent from current levels) that offset the decline in other four forest management types.

High woody biomass consumption—Compared to the medium- or low-consumption scenarios, this scenario assumes that a larger share of the U.S. energy portfolio is sourced from woody biomass (fig. 10-11); with prices reaching five times the 2007 level for softwoods, and eight times the 2007 level for hardwoods. Inventory and harvest levels for softwoods are higher compared to low- or no-consumption scenarios, but lower than the medium scenario; for hardwoods, inventory levels are much higher than the no- or low-consumption scenarios and removals are higher than all other scenarios. The pulp industry is adversely impacted as significant supplies are diverted to energy production (fig. 10-12). The bioenergy requirement is not met by new removals, pulpwood, or harvesting residues, resulting in a complete elimination of forest industry demand for hardwoods by 2037 followed by softwoods in 2043.

The prices, inventory, and removal levels of sawtimber are similar to the other consumption scenarios. The industry would experience a significant impact as 91 million green tons of sawtimber is diverted to energy production. The increased acreage of pine plantations might result in some of the softwood timber moving to sawtimber diameters. Significant amounts of hardwood sawtimber are also diverted to energy production.

Private forest acreage increases by 9 percent from 175.39 million acres in 2010 to 191.6 million acres in 2050 (fig. 10-13), 21 percent higher than the no-consumption scenario. All forest management types except natural pines increase in area by 2050, led by a 33 percent increase in pine plantation acreage. Initial acreage declines for upland and lowland hardwoods and oak-pines are reversed after 2027, resulting in a 2-percent net increase by 2050.

Supply Adjustment Strategies

Increased consumption for wood by a new woody bioenergy industry can be expected to result in the supply side adjustments such as the use of short rotation woody crops and the increased productivity strategies described below.

Productivity increases limited to pine plantations—An increase in pine plantation productivity would do more to dampen nonsawtimber softwood price increases in the medium- and high-consumption scenarios (fig. 10-14) than in the no- and low-consumption scenarios (which do not stimulate productivity gains), with prices falling until the late 2020s before beginning to increase again. Inventory and removals levels are also higher. The increase in productivity of pines also lowers price responses for hardwoods, largely because increased softwood inventories fulfill the demands for bioenergy.

Figure 10-15 shows price, inventory, and removal projections for sawtimber under medium-and high-consumption scenarios. For softwood sawtimber, productivity increases in pine plantations also result in lower prices and higher inventory and removals under both increased productivity strategies, with the medium-consumption scenario providing a greater price dampening effect than the high-consumption scenario. Price trends are the same for hardwood sawtimber but the decreases are less extreme. Higher inventory levels result from the increase in productivity, which reduces prices. The impact on the sawtimber-using industry is also reduced. For example, in the high-consumption scenario 54.5 million green tons of sawtimber from both hardwoods and softwoods is diverted to energy use in the pine productivity strategy as compared to 91 million green tons associated with no productivity increases. The decreased impact on the forest industry is due to expanded removals supported by increased productivity.

Productivity increases result in higher removals and less displacement from forest industry (fig. 10-16). The softwoods being used by forest industry are still completely diverted for energy production in the high-consumption scenario, but this occurs later.

Forest management type trends are similar for the medium-and high-consumption scenarios, with increases in pine productivity resulting in lower levels of private forest acreage for both scenarios (fig. 10-17)—9.6 percent for the medium- and 10.2 percent for the high-consumption scenario—albeit much higher than for the no-consumption scenario. Because productivity gains are limited to softwoods, a higher share of the wood requirements for woody bioenergy markets is met by softwoods than hardwoods. Acreage declines across all five management types, with the highest rate of decline in pine plantations.

Productivity increase extended to all management types—A productivity increase for all forest types results in price, inventory, and removal responses that are similar to those observed for increases in pine plantations alone, the only difference being in the magnitude of change. Softwood price is lower and inventory and removal levels are higher (fig. 10-18). Hardwood trends for medium- and high-consumption scenarios are similar to the softwoods, with lower prices and higher inventories and removals than was projected for planted forest types alone (fig. 10-19).

Nonsawtimber softwoods used by forest industry are still completely diverted to energy production in the high-consumption scenario, but the impact on the sawtimber-using industry is reduced. For example, in the high-consumption scenario, 36.38 million green tons of sawtimber from is diverted to energy use as compared to 53.5 million green tons with pine productivity alone and 91 million green tons with no productivity (fig. 10-20). Higher removals of sawtimber are attributed to unharvested pulpwood timber moving into the higher diameter sawtimber class. The productivity increases therefore result in higher acreage and higher inventory at the aggregate level.

Compared to planted-pine-alone productivity strategy, this approach increases total forest area for both medium-consumption scenario (165.52 million acres) and the high-consumption scenario (175.01 million acres), with acreage increases for all forest management types except pine plantations (fig. 10-21).

Low productivity increase—Lower productivity increases combined with medium- and high-consumption scenarios result in price, inventory, and removal responses similar to the all productivity increase strategies (fig. 10-22 to 10-23).

The supply response of the low productivity strategy fails to offset the woody biomass requirements, with all nonsawtimber softwood being diverted from forest industry to energy production under the high-consumption scenario and a significant amount diverted under the medium-consumption scenario (fig. 10-24). The impact on the sawtimber-using industry is higher than for the all productivity or pine productivity strategies, but lower than if no productivity measures were taken. For example, in the high-consumption scenario, 57.18 million green tons of sawtimber is diverted to energy use as compared to 36.38 million green tons for the all productivity strategy, 53.5 million green tons for the pine productivity strategy and 91 million tons if no productivity measures were taken.

Private forest acreage is higher than for the other two productivity strategies. Forest land decreases from 175.39 million acres in 2010 to 172.47 million acres for the medium-consumption scenario, but increases to 181.85 million acres for the high-consumption scenario (fig. 10-25). Planted pine acreage increases more and other forest type acreage declines less as compared to the pine productivity or all productivity strategies.

Productivity increases on short rotation woody crops—We ran the model to simulate the results of a high productivity strategy coupled with the emergence of short rotation woody crops in the South. Inventories and removals (fig. 10-26) are higher than for the all productivity strategy coupled with high consumption (similar to results from a subsequent run combining a low productivity strategy with short rotation woody crops). Softwood and hardwood inventories are higher compared to the no-consumption scenario. Price increases for all products are dampened.

These results also suggest that the pulp industry would still face adverse impacts, as merchantable wood from forest industry would be diverted to energy production (fig. 10-27). However, the combination of increased supplies from short rotation plantations and from productivity gains on existing forests would provide most of the 'additional' sawtimber needed for energy production, resulting in just 26.7 million tons diverted from forest industry. The higher levels of aggregate inventory and removals counter the notion that diverting wood for energy would necessarily lead to inventory declines. Forest acreage is lower than for the other productivity strategies, but higher than the no-consumption scenarios (fig. 10-28).

Technologies

Considering the potential availability of wood that could be used in the traditional forest product industries and woody bioenergy industries, it is important to determine how current and likely suitable wood-to-energy conversion technologies can potentially impact the future of southern forests (for example, how technological preferences towards a particular species might increase its price, producing changes in inventory and removal). Dwivedi and Alavalapati (2009) found that a broad spectrum of stakeholders view conversion technologies as one of the main weaknesses for the development of forest biomass based energy in the South. In addition, Nesbit and others (2011) found that under current levels of technology, slash pine ethanol is not a financially viable competitor for fossil fuels. They found that unit cost of producing ethanol from slash pine (Pinus elliottii) through a two-stage dilute sulfuric acid conversion process, and a synthesis gas ethanol catalytic conversion process was estimated to be $2.39 per gallon and $1.16 per gallon respectively. If adjustments are based on the lower energy content of ethanol relative to gasoline (Oak Ridge National Laboratory 2008), the cost of an energy equivalent gallon of ethanol increases to $3.55 and $1.74 per gallon for the two conversion processes, respectively.

Woody biomass can be converted into energy using a number of different processes. Broadly speaking, wood-to-energy conversion technologies can be grouped into two main categories: thermal technologies—such as co-firing and combined heat and power, direct combustion using wood pellets and wood chips, gasification and pyrolysis—and biochemical processes.

Co-firing and Combined heat and power—Combustion of woody biomass can be applied to produce heat and electricity, particularly in industrial and residential sectors. Three major technology options are being developed for producing electricity and heat. These are: setting up dedicated cellulosic power plants, co-firing biomass in existing coal plants, and developing combined heat and power plants. All these options are being explored in the South, ranging from a dedicated power plant that will use urban wood waste, wood processing wastes, and logging residues in Gainesville, Florida to plants that blend biomass with coal or inject biomass separately into boilers. Currently, 27 co-firing plants supply a biomass/coal co-firing capacity of 2,971 megawatts. Virginia is the leader in the number of co-firing plants and capacity in the South, followed by North Carolina in terms of co-firing plants, and Kentucky in terms of co-firing capacity (fig. 10-29).

Combined heat and power plants are smaller and have lower electrical efficiency than co-firing plants, but they use a similar combustion system to generate heat and electricity. The primary product for small plants is heat, and electricity for the larger ones produce electricity as the primary product (Jackson and others 2010). They generate a net summer capacity of 20,336,000 megawatt-hours about 127,880 billion Btu of biomass fuels including agricultural crop byproducts, municipal solid waste, wood and waste solids, black liquor, sludge waste, wood waste liquids, and landfill gases. The South represents about 58 percent of the total consumption of biomass and 65 percent of the net generation of biomass-based electricity in combined heat and power plants (fig. 10-30). While it helps improve overall conversion efficiency, the Scandinavian-style community-based CHP systems might not work in the US South. Most of the existing CHP use in the South is associated with the paper, pulp, and forest products industries. However, other entities are also focusing on CHP generation. For example, the Department of Energy is slated to replace coal for a steam plant at its Savannah River Site with woodchip and other biomass, while Baycorp Holdings Ltd. and the Nacogdoches Economic Development Corporation gained approval to set up first woody biomass electricity plant in Texas.

Direct combustion using wood pellets and wood chips—Wood pellets, compressed byproducts from forest industry such as sawdust and woodchips, are used as fuel for domestic heating and for combined heat and power plants. These high-density pellets are characterized for having high energy content (about 40 percent higher than wood chips with 30 percent moisture content by mass and more than 300 percent by volume), being of uniform size and shape (facilitating automated handling), and being economically attractive. Rather than just using sawdust from mills for producing pellets, companies have built plants that use whole trees and chips as well. In the recent past, some of the largest pellet producers in the world have been established in the South, with 24 mills contributing about 46 percent of the country's 2 million ton annual capacity (Pellet Fuels Institute 2010, Spelter and Toth 2009). The States with the largest number of wood pellet mills are Georgia, Kentucky, and Virginia (fig. 10-31).

Gan and Mayfield (2007b) suggest that forest biomass, in general, is not cost competitive with coal for electricity production. Gan and Smith(2006a) through their comparative analysis of wood and coal based electricity found that the production cost of short-rotation woody crops was $10.80 per Megawatt hour, more than double the national average price of delivered coal based electricity in 2005 ($5.32 per Megawatt hour). Even the electricity from logging residues ranged between $47 to $50 per megawatt hour (Gan and Smith 2006b). Drawing from a study conducted in 15 Western States, the estimated costs for procuring biomass from forest fuel treatment thinnings range from $6.20 to $8.30 per Megawatt hour for cut and skid treatment, while this increases to cost $7.00 to $9.90 per Megawatt hour in cut/skid/chip method (United States Forest Service 2005).

Other thermal technologies—Other thermal technologies (also known as advanced thermal technologies) are gasification and pyrolysis, both of which are technically feasible. Gasification is a high temperature process in which biomass is used to generate different bioproducts such as heat, electricity, methanol, ethanol, and syngas (hydrogen). If the gasification process includes a devolatization and conversion of biomass in a steam environment, it can produce a medium calorific gas that can be transformed into fuel for combined cycle power generation (Guo and others 2007). Otherwise, the syngas is converted to ethanol or hydrocarbon chemicals and fuels. Nexterra has commercial gasification units in British Columbia (Tolko and Kroger) using wood waste as a fuel source.

A similar wood based gasifier is being set up in University South Carolina by Nexterra. Pyrolysis is a type of gasification technique that converts biomass at higher temperatures in the absence of oxygen to bio-oil (fast pyrolysis) and charcoal (slow pyrolisys). Bio-oil can be used as fuel in heating or electrical applications and for production of chemical commodities (Faaij and Domac 2006). Converting woody biomass to bio-oil increases energy density, which translates to improved transportability. Its main disadvantages are low heating value, poor ignition performance, and thermal instability (Jackson and others 2010). The pyrolysis plants are not yet commercially viable for large scale production.

Biochemical—Processed biodiesel and ethanol (fig. 10-32) are the primary liquid fuels that can be derived from biochemical processes. Wood-based ethanol can be obtained through hydrolysis and fermentation. Cellulose and hemicellulose are broken down into sugars in hydrolysis, which are then fermented to generate ethanol.

Two hydrolysis stages are currently in practice: thermal, acid, alkaline, and biological pretreatments followed by an acid or enzymatic treatment. Hydrolysis and fermentation can be conducted separately or simultaneously. Separate processes are more expensive and have lower ethanol yields, but they allow each to be carried out at its optimal temperature (Jackson and others 2010).

Although several hydrolysis techniques have gained momentum in the last decade, efficiency and cost issues have hindered commercial viability. An integrated enzymatic process could contribute to cost reductions, but it has not yet moved out of the laboratory stage.

The Department of Energy set 2012 commercialization targets for research and development which included reducing the selling price of ethanol by 2012 to $1.07 rather than $1.61 per gallon, increasing ethanol yield per dry ton from 56 gallons in 2005 to 67 gallons in 2012, and reducing installed 2005 capital and operational costs by 35.5 percent and 65.3 percent respectively. For fermentation based ethanol production, the target is to increase yield from 65 gallons per ton in 2005 to 90 gallons per ton in 2012. The target also sets feedstock cost target for 2012 as $35 per dry ton. Efforts are ongoing to achieve these targets, but no technological breakthrough has yet achieved these large scale production targets. The Range Fuel plant in Soperton, Georgia produced waste wood methanol in August 2010, and currently producing its first batch of cellulosic ethanol. However, the plant is shutting down operations after demonstrating its cellulosic production technology. The scale of bioenergy plant in terms of capital and biomass demands from the forest landscape are issues that need further attention. If a large plant is set up, then the transportation cost of procuring biomass from areas farther from the plant site might increase per unit cost and/or lead to procuring lower quality feedstock. The scale of the plant not only depends on cost issues, but also on the purpose for which it is being built. For example, Van Loo and Koppejan(2008) suggest that small combined heat and power plant facilities with lower conversion efficiency (10 percent) can be used where heat is the primary product with power as the secondary product, while facilities (more than ten megawatts) generally have higher efficiency (25 percent) as they produce electricity as the primary product.

The Policy Environment

A number of current and proposed policies and programs may influence the future of woody biomass-based energy markets in the South. Some of these policies are directed specifically at the expansion of woody biomass use for energy, and others influence indirectly by focusing on reductions of greenhouse gas emissions.

Incentive-based policies provide financial support such as cost-shares, tax reductions, subsidies or grants, and low- or no-interest loans for project financing. The Database of State Incentives for

Renewable and Efficiency (2010) reports that policies for renewable energy (including woody biomass for energy) in the Southern States are in the form of tax rebates, grants, loans, industry support, bonds, and performance-based incentives.

Regulatory and support mechanisms include policies that set goals, targets, and limits; and compel certain types of behavior, as well as creating supportive infrastructure and facilitating public educational outreach. Rules, regulations, and policies (regulatory and support policies) are in the form of public benefit funds, renewable portfolio standards, net metering, interconnection standards, contractor licenses, equipment certification, access laws, construction and design rules, green power purchasing guidelines, and green power policies.

Incentive-based policies—In an effort to support market-based solutions, Federal and State governments have introduced a number of incentive-based policies. This generally results in altering prices by assigning a monetary value to something that was previously external to market forces (Shrum 2007). Subsidies are intended to encourage planting and management activities that might promote feedstock availability, and tax support encourages the use of renewables. Support in the form of grants and loans are also provided to encourage clean technology development and adoption.

Incentives for liquid biofuels were first instituted in the Energy Tax Act of 1978, which provided a $0.40 per gallon exemption from the gasoline excise tax for blends with at least 10 percent ethanol. Then it was increased to $0.51 per gallon by the 1998 Transportation Equity Act of the 21st Century. The American Jobs Creation Act of 2004 replaced the excise tax exemption with a volumetric ethanol excise tax credit of $0.51 per gallon until 2010 (reduced to $0.45 per gallon by the Farm Bill of 2008). The Energy Independence Security Act (2007) provided a production tax credit of $1.01 per gallon for cellulosic biofuels through 2012. The following section summarizes the current bioenergy policies in the South.

The 2008 U.S. Farm Bill created a new Biomass Crop Assistance Program (BCAP) to encourage development of large-scale energy crops that can support commercial-scale bioenergy production. BCAP provides incentives to farmers, ranchers and forest landowners to establish, cultivate and harvest biomass for heat, power, bio-based products and biofuels. The program shares the establishment cost and matches cost related to transportation and logistics up to $45 per ton to producers with user facilities contracts. The program reduces the financial risk to farmers and forest landowners to supply eligible biomass materials to qualifying facilities, and can reduce the cost of raw materials to the facility. These also promote conservation and stewardship by emphasizing that biomass is collected and harvested according to an approved conservation, or similar plan to protect soil and water quality and preserve future land productivity.

Rebates followed by loans are the most popular financial incentives in the South (table 10-4,). The 17 Federal financial incentives are mainly comprised of corporate tax rebates, research and development grants, and loans. Loans and performance-based incentives are the policies most frequently used in the 76 State financial incentive programs. North Carolina has the largest number of State financial incentives (eight), and Texas has the smallest (two).

Few State programs are specifically aimed at increasing woody biomass stock for energy use, partly because wood-for-energy markets have not yet been established. However, more often than not, improvement in forest biomass availability and sustainable use is an offshoot although not the overarching goal of these programs. Although the minimum acreage and stocking levels for property tax calculations vary across Southern States, the general objective of all these taxes is to provide an incentive for managing land on a sustained yield basis and a disincentive for converting forest land to other uses. The objectives of State cost-share programs are to reforest cutover land, plant open land, or improve woodlands; and many States offer to sharing costs of forest management activities. For example, South Carolina has forestry commission cost-share programs and North Carolina has forest agriculture cost-sharing programs. These programs lead to higher availability of feedstocks for energy conversion.

Several federal programs provide incentives for conservation of forestlands and maintaining sustainable forest management practices. For example, the Environmental Quality Incentives Program (EQIP) provides cost shares for installing greenhouse gas mitigating technologies and Landowners Incentive Program provide financial assistance to landowners for a variety of conservation goals including carbon sequestration. The Forest Land Enhancement Program promotes additional carbon sequestration and other ecosystem services through cost shares with landowners. These programs help to reduce land use change away from forests, in turn indirectly maintaining the forest stock that can be used for energy production at a later date. Incentive programs for reforestation have also been established in a number of States. For example, Mississippi provides tax credits for reforestation.

Regulations and support programs—At the Federal level, the Energy Policy Act of 2005 established Renewable Fuel Standards, which mandated that transportation fuels contain a minimum volume of renewable fuels, starting with 4 billion gallons in 2006 and 7.5 billion gallons by 2012. The Energy Independence Security Act (2007) called for production of 36 billion gallons of biofuels by 2022, of which 21 billion gallons must be cellulosic biofuel. The 2008 Farm Bill authorized mandatory funding of $1.1 billion for the 2008 to 2012, providing grants and loans to promote alternative feedstock resources including woody biomass. Interconnection standards and green power purchasing have also been formulated at the Federal level.

Construction and design support for establishment of bioenergy production facilities and net metering available to biomass based energy facilities so they can sell power back to the grid are the most employed State-level policies in the South and 10 Southern States have also formulated renewable portfolio standards as targets for using cleaner sources of energy in utilities and industries .

Extension and support activities have facilitated knowledge transfers, technology demonstrations, and information sharing sessions; and have developed multi-stakeholder partnerships to reduce greenhouse gas emissions. Extension agents and specialists at land-grant universities and government institutions transfer knowledge about natural resource management (including woody biomass-based energy) to client groups, such as forest owners, foresters and other natural resource managers, tree growers, loggers, and forest workers. Non-state efforts aimed at landowners include a State Tree Farm program that recognizes landowners who are doing a good job of managing their land with a certificate, subscription to Tree Farm magazine, and Tree Farm sign to display on their property. Regular interaction between landowners and professional foresters is facilitated through periodic visits by foresters.

There have been number of efforts by US policymakers to create markets as a mechanism to regulate GHG emissions, although no bill has yet become law. For example, the House passed the American Clean Energy and Security Act (aka Waxman-Markey) on June 26, 2009, and three other bills were submitted to the Senate in 2009 and 2010: the Clean Energy Jobs and American Power Act (Kerry-Boxer), the American Power Act (Kerry-Lieberman), and the Carbon Limits and Energy for America's Renewal Act (Cantwell-Collins). Waxman-Markey, Kerry-Boxer, and Kerry-Lieberman would create markets for emitting and offsetting carbon dioxide and permit the purchase of up to 2 billion metric tons of carbon offsets annually (Mercer et al. 2011). Gorte and Ramseur's (2008) estimate that at a CO2e price of $50 per metric ton, more than 800 million metric ton of CO2e could be sequestered through afforestation activities, and approximately 380 million metric ton through improved forest management activities.

Forestry offset projects including mitigation of green house gases through bioenergy production can potentially accrue carbon credits but the accounting is challenging. Assuming that energy crops do not lead to land use changes, life cycle analyses of different biofuels (including woody biomass) suggest overall green house gas reductions (Blottnitz and Curran 2006, Eriksson and others 2007, Gustavsson and others 2007). Searchinger and others (2008) argue that life cycle studies have failed to factor in indirect land use change effects, and suggest that using U.S. croplands or forestlands for biofuels results in adverse land use effects elsewhere, thus harming the environment rather than helping it. Indirect land use change effects are difficult to assess, and today there is no generally accepted methodology for determining such effects. Fritsche and others (2006) argue for assessing indirect influence of bioenergy on land use change through measures such as land prices and rents. However, conducting such assessments at the site level and translating these to operational indicators is quite costly. A satisfactory methodology for incorporating the effects of indirect land use changes into the lifecycle greenhouse gas emissions of fuels remains an important challenge.

There are also policies and regulations that could limit development of a bioenergy industry in the South. The Environmental Protection Agency's final Greenhouse Gas Tailoring Rule, does not exempt biomass power producers from greenhouse gas permitting requirements, and might act to limit the establishment of bioenergy conversion plants. This rule treats carbon emissions from biomass combustion identically to fossil fuels emissions and increases costs associated with obtaining permits and costs associated with technology requirements, such as Best Available Control Technology. Mendell and others (2010) suggest that regulatory uncertainty created due to this regulation could affect establishment of 130 renewable energy projects, and $18 billion in capital investment across the country. Similarly, the Environmental Protection Agency's air quality permitting for biomass boilers impacts biomass based electricity producers adversely.

Assessing efficacy of policies—A number of researchers suggest that private landowners are by and large unresponsive to property tax and capital gains provisions, and that forest property tax programs are only modestly successful in achieving their goals (Greene and others 2005, Kilgore and others 2007, Jacobson and others 2009). Many authors have found that landowners are largely unaware of the existence of incentives or do not understand how incentives might apply to them. For example, Butler (2008) based on landowner responses to the U.S. Forest Service's National Woodland Owner Survey, concluded that not all landowners are price-responsive. Factors such as maintaining forest land for aesthetics or wildlife conservation, as well a movement towards smaller ownerships, might be responsible for this price unresponsiveness. Nevertheless, at aggregate level, these incentive based policies result in increased welfare, as shown by Huang (2010) who found that when combined with investment in technology, they can result in overall positive outcomes for South's economy and household welfare.

Beach and others (2005) and Greene and others (2005) found that nonindustrial private forest owners more often respond to targeted government programs than to market prices or other financial incentives. They also suggest that technical assistance, cost-share payments, and direct contact with professional foresters or natural resource specialists more often than not succeed in changing forest management decisions. Authors like Haines (2002) and Arnold (2000) have proposed integrating land use planning (and woody biomass-based energy use) into extension programs. Educating landowners and the general public about the benefits derived from cleaner energy sources such as woody biomass will improve and increase interest in forest biomass utilization. Mayfield and others (2008) indicated that education and community engagement play important roles in the development of cleaner technology like wood-based energy. Joshi and Arano (2009) agree that landowners are largely unaware of incentive programs available to them, and thus argue that much remains to be done to encourage private investment in forestry activities. In light of these findings, extension and outreach support programs become important for increasing the acceptability of wood-for-energy technology options and improving forest and land management practices.

Sustainability

The development of forest bioenergy systems presents new opportunities as well as risks. Many sustainability concerns are being raised about wood biomass utilization for energy. These concerns range from production processes to consumption processes—feedstock production, harvesting, transport, conversion, distribution, consumption, and waste disposal—and include issues of job creation and societal benefit distribution.

Forests provide not only wood for traditional uses, but also several ecosystem services such as clean water, habitat for flora and fauna, maintenance of biodiversity, hunting, fishing, and other recreational opportunities. In light of Federal and State policy initiatives favoring renewable technologies, it is quite likely that the demand for larger harvests and higher removal intensities might increase. Depending on management approaches, increases in harvesting such as those simulated in this chapter could lead to undesired impacts on forest habitat integrity as documented in studies worldwide, such as reduction of soil and stand productivity (Burger 2002; Stupak and others 2007); changes in species composition, local communities, flora, and fauna (Amacher and others 2008); and negative effects on watercourses and biodiversity (Neary 2002: Stupak and others 2007). These potential impacts—grouped into productivity, water quality, and biodiversity categories—are described in detail below.

Productivity—The forest floor accumulates nitrogen, phosphorus, calcium, and other nutrients that are essential for tree growth. Unlike traditional timber harvests, biomass harvests for energy production could impact regeneration and site productivity unless productivity reductions associated with site quality are offset by fertilization. Studies of forest biomass based energy production raise concerns regarding soil compaction and rutting (for e.g., Reijnders 2006), decreased amounts of decaying wood on forested landscapes, changes in the chemical and physical environment of soils (for e.g., Astrom and others 2005), increased use of agrochemicals (e.g., Fritsche and others 2006), increased soil erosion (e.g., Burger 2002), and nutrient loss (e.g., Burger 2002). These issues suggest a need for intensified site and off-site monitoring where forest management is intensified.

The machinery used to build roads and infrastructure for biomass harvesting biomass for energy might be different from what was used in traditional timber harvesting and harvesting might take place in areas where timber harvesting is traditionally not undertaken, resulting in new roads or pathways (Smith and Lattimore 2008, Lal and others in press). Frequency of harvests for biomass removal could also be generally higher than for traditional harvests, and second operations or harvest residue collections might result in vehicle re-entry at the site (Lal and others 2009). Intensive removals of forest biomass for bioenergy might reduce soil carbon and organic matter to levels that are inadequate for sustaining forest productivity. Hope (2007) through their site experiments in British Columbia observed that stump removal decreases the soil stock of carbon by 53 percent, nitrogen by 60 percent, and phosphorus by 50 percent; and that the forest floor depth was decreased by 20 to 50 percent. Peng and others (2002) through their study in Central Canada reported that whole-tree harvesting produces an additional 32 percent loss of soil carbon compared to conventional tree harvesting. Smith and Lattimore (2008), while discussing potential environmental impacts of bioenergy harvesting on biodiversity list contributing activities such as mechanical damage to residual trees; expanded road networks; increased removals and land use changes that might impact productive and diverse ecosystems. Scott and Dean's (2006 Long Term Site Productivity Study found that whole-tree harvesting reduced productivity on over 75 percent of the study blocks in South by an average of 18 percent. However, they also found that a one-time application of Nitrogen and Phosphorus fertilizer maintained productivity and increased productivity by an additional 47 percent above the stem-only harvest level.

Harvesting slash remaining after conventional harvesting of loblolly pine (*Pinus taeda*) in the Coastal Plain along the Gulf of Mexico reduced site productivity, decreasing soil organic matter and associated nutrients by 18 percent (Scott and Dean 2006). Reductions of jack pine (*P. banksiana*) height growth of 18 percent on whole-tree harvested plots in sites of Quebec region of Canada were attributed to lower soil moisture and nutrient availability (Thiffault and others 2006). To avoid decreased productivity from soil compaction during biomass harvesting, Janowiak and Webster (2010) after reviewing the state of knowledge regarding the impacts of intensive forestry with respect to issues relevant to bioenergy production, recommended using machinery that is similar to what is used in conventional harvesting.

Water quality—Increased biomass harvesting activities for a wood-to-energy market might have adverse impacts on water quality in streams, rivers, and lakes. Increased road construction required for woody biomass harvesting might lead to soil erosion, high soil moisture, and increased runoff and sediments from forest roads and landings (Janowiak and Webster 2010). Increased machinery use might also impact the water table at the harvest site, leading to impermeable soils from compaction. Removal of younger trees and lopping and topping during biomass harvests might decrease leaf surface area, resulting in decreased transpiration and interception (Lal and others 2009).

Machine re-entry at harvest sites might increase sedimentation and flow levels in waterways, increasing the chances of sediment movement into wetlands through damaged erosion control features. Frequent harvests might increase suspended solids and aluminum levels in water, raising acidification levels and negatively impacting fish and other aquatic organisms (Grigal 2000). In addition, woody biomass harvesting adjacent to waterways might increase the probability of higher water temperatures, disturbed chemistry, and reduced clarity that would damage biological communities and alter ecological processes (Janowiak and Webster 2010). Aust and Binn (2004) reviewed best management practices for timber harvesting and site preparation in the eastern United States in terms water quality and productivity research during for the time period 1982 to 2002 and concluded that effects of harvesting on forest hydrology are highly variable across sites and time periods. However, harvesting impacts on forest hydrology are likely to be greater immediately following harvest, with the recovery to preharvest conditions taking up to 5 years

Biodiversity—The extraction of additional biomass for bioenergy could degrade habitats beyond the range of natural variability and produce negative effects on some species (Janowiak and Webster 2010). Increased access and intensity of harvest can also fragment habitats and adversely impact wildlife corridors (Fletcher and others 2011; Lal and others 2009). Natural disturbances such as fire, wind, and pest outbreaks permit a continuous supply of deadwood in unmanaged forests. Intensive forest management leading to removal of stumps might reduce the amount of deadwood that is considered essential to forest ecosystems and provides habitats for different organisms (Humphrey and others 2002).

The removal of residues and stumps might negatively alter the entire soil fauna community and structure of the food web, harming small mammals, and reducing ecological niches, thereby lowering diversity and numbers of invertebrates such as spiders and predatory insects (Ecke and others 2002). There is also a chance of insects or other wood-colonizing species getting trapped in wood burnt for fuel.

However, intensive forest management practices controlling pests and disease can also improve forest habitats. For example, certain fungi species cause root and butt rot disease to conifers worldwide. Stump removal associated with whole-tree harvesting generally leads to significant reductions in the area of the stump colonized by these fungi, reducing the risk of attack (Thor and Stenlid 2005). Conversely, the harvesting of forest residues and stumps would also favor pioneering species of flora that are also more tolerant of exposure and soil moisture levels. When all biomass is removed, growth these species is more vigorous, particularly the invasive nonforest field vegetation, which—if it is not managed—might lead to a reduction in timber productivity (Walmsley and Godbold 2010). Scott and Dean (2006) also suggest that in the Gulf Coastal Plain, soil analyses could be used to identify harvesting sites at risk of harvesting-induced productivity loss, and fertilization treatment could be used to avoid productivity loss caused by whole-tree harvesting.

Fletcher and others' (2011) meta-analysis of studies on crops being used or considered in the U.S., found that vertebrate diversity and abundance are generally lower in biofuel crop habitats relative to the non-crop habitats. They found diversity effects are lower for pine and poplar than for corn, and birds of conservation concern experience lower negative effects. However, for minimizing impacts of biofuel crops on biodiversity, they suggest practices that reduce chemical inputs, increase heterogeneity within fields, and delay harvests until after bird breeding. Many of these practices might already be incorporated under intensive management regimes in South and could be incorporated into biomass production systems and management planning used to avoid adverse impact on forested landscapes.

Results of direct and indirect land use change to agricultural row systems can also cause habitat loss (Jonsell 2007). The land use change from natural forests to forest plantations, including short rotation woody crops, is of the greatest concern from an ecological point of view (Wear and others 2010). Interventions focused on ecological restoration or fuel reduction activities associated with woody biomass would also benefit wildlife habitat (Janowiak and Webster 2010). However, biomass production might also have negative consequences unless coordinated with breeding and nesting seasons and maintaining cover for overwintering small mammal species (Bies 2006).

Just as important to southerners, but less quantifiable, are the potential impacts of increased woody biomass removals on quality-of-life issues: aesthetics, community relationships, and appreciation of forest land as an integral part of the social and physical landscape (Wear and others 2010).

Discussion and Conclusions

Markets

Our demand analysis shows that the consumption requirements for wood from bioenergy markets would not likely be met by urban wood waste alone, and that demands for woody biomass would require harvesting residues or biomass from timber markets by 2013 (fig. 10-2). Prices for all forest products would likely increase, resulting in increased returns to forest landowners. Price changes are greater than changes in removals or inventory, consistent with an inelastic market response. Although removals are responsive to price changes (higher removals at higher prices), forest inventories will also depend on factors like forest growth, afforestation of agricultural or pasture lands, intensive management of forest land, and increased plantations of fast growing species. The models used for our analysis attempt to account for these factors, but future conditions are clouded by large uncertainties about demand and supply factors. Consistent with chapter 4, the market model indicates that increased prices under bioenergy futures would mitigate the loss of forest land in the future. Planted pine forest area is the most responsive to these price trends. Bioenergy demands would result in declining use of timber by forest industry, with impacts more pronounced for pulp based industries than for sawtimber industries.

With high demand for woody biomass, sawtimber industries could also be impacted, although at lower levels. This projection is consistent with studies by Aulisi and others (2007) and Galik and others (2009), who found that pulpwood markets are more likely to be impacted by an emerging wood-based energy industry. Furthermore, Aulisi and others (2007) suggest that sawmills might benefit from the higher prices paid by bioenergy markets for secondary products such as sawdust and chips. Our simulation indicates that at high levels of bioenergy demands, the softwood sawtimber industry would eventually be adversely impacted.

Forest industry might also face increased feedstock prices for their pulp and sawtimber operations. In the long run, price increases for softwood nonsawtimber are less severe than for hardwood nonsawtimber because pine plantation area can respond quickly, and hardwood plantations are not common in the South.

Increased forest productivity could moderate price growth and result in higher rates of removals and inventories. Although productivity has grown substantially in the South as a response to intensive management and genetic improvements, productivity effects are not limited to softwoods. Price increases are smallest with productivity growth strategies that extend to all management types along with an increase in short rotation plantations. Expanding demands for bioenergy would not necessarily reduce the levels of forest inventories. Our simulations show that an increase in demand from the energy industry, coupled with productivity increases, could lead to higher levels of both removals and inventory.

With management and technological advancements, woody bioenergy markets could result in increases in inventory, removals, forest acreage, and returns to landowners. Southern forests could be managed to produce substantially more timber for bioenergy and other forest products consistent with the projections shown in chapter 9.

These results indicate that the future trajectory of southern forests will depend on the state of wood based energy markets as influenced by technological developments and cost considerations. Markets will also be shaped by other unknowns, including the amount of renewable energy that will come from solar, wind, and other sources of renewable energy. Similar to any nascent industry, the future of wood based energy will depend on a number of uncertainties, including the costs of production, technological breakthroughs, the government policies that support renewable technologies, forest productivity decisions, and the expansion of short rotation woody crops, are a few of the factors that might determine the future of this industry[2]. Along these lines, if carbon markets emerge and carbon credits for displacing fossil fuels with woody bioenergy are considered, more changes in forest management and short rotation woody crops might be expected, but inclusion of these details is beyond the scope of this chapter.

Technologies

On the woody biomass-based energy technology front, there is no emergent favorite. Even supposedly “low-hanging fruits” such as co-firing face significant challenges, such as boiler ash deposition, corrosion, and feedstock selection. Federal and State governments, along with forest industry, are investing research dollars into these technologies with hopes of commercial success. Different types of woody bioenergy occupy different places on the cost feasibility spectrum. Wood pellets are already feasible under current markets, while biofuels are not economically competitive at the current level of technology.

Advantages of wood pelletization include high energy-to-weight ratio, lower capital requirements, ability to operate production facilities at a variety of scales based on demand or wood supply, lower costs of shipping the final product, easier handling, and, most of all, high demand in European countries. Conversely, preferred conversion technologies for wood-based fuels remain largely uncertain because of the high cost of production, project-specific factors, and environmental standards (McKendry 2002). The high unit cost of woody biomass-based energy is largely attributed to high harvesting and transport costs; for example, making woody biomass-based ethanol competitive with starch-based ethanol or gasoline would require reduced capital costs through technology improvements, reduced feedstock costs (primarily from yield improvement), and densification of wood at the harvest site to lower harvesting costs (Dwivedi and others 2009, Jackson and others 2010, Alavalapati and Lal 2009). The cost of transport from the supply source (for example, the forest) to the conversion plant also determines the viability of the manufactured product (electricity, heat, or liquid fuels). Overcoming this significant challenge requires that plants have easy access to the wood supply and to distribution markets.

No species group has emerged as a favorite for woody bioenergy. Both softwoods and hardwoods can be co-fired with coal, used in combined heating and power plants, and compressed for wood pellet production (Spelter and Toth 2009). Evidence supporting a clear preference for hardwood or softwood species for wood-based liquid fuel is lacking as well. Zhu and Pan (2010) suggest that sulfite pretreatment to overcome lignocelluloses recalcitrance process holds promise for woody biomass conversion, especially for softwood species. However, softwoods contain more lignin than hardwoods (Galbe and Zacchi 2002), meaning that the conversion to liquid fuels might be less efficient in softwoods because lignin needs to be removed during the pretreatment process. Even Zhu and Pan (2010) noted that in one of the most common pretreatment processes (acid catalyzed steam explosion) sugar was successfully recovered from hardwoods (for example, 65 to 80 percent recovery from poplars) compared to less encouraging results for softwood species.

Regardless of the conversion technology employed, a continuous long-term flow of wood would be needed as raw material. Because many Southern States are emphasizing renewable technologies, new co-firing and combined heat and power plants and ethanol biorefineries are likely to be established in the future. Expansion of this sector—more woody biomass-based energy plants or expansion of existing facilities to achieve economies of scale—will be associated with an increase in the demand for wood fiber. To meet the burgeoning demand for woody biomass for energy estimated by SRTS simulation runs, merchantable timber and small-diameter wood would be required in addition to logging residues or wood waste such as sawdust, shavings, and chips from other wood product manufacturing processes.

Technological advancements are essential for making wood energy competitive with other sources such as gasoline and coal. Policy support for woody biomass-based energy, a nascent industry, might help in attaining commercial viability and developing a mature market.

Policies

Available policy instruments have advantages and disadvantages (Aguilar and Saunders 2010). Financial incentives allow directly measurements of their impact on prices. Moreover, they can promote sustained demand for and supply of energy feedstocks, and can lower the capital costs of investments. However, funding for these programs is vulnerable during hard economic times. Regulations such as renewable portfolio standards are easy to adopt, and producers generally bear incurred costs. However, these types of policies might suffer from inflexibility, and information needed for effective targeting can be elusive. A better option might be to develop a suite of policy options geared towards woody biomass-based energy. For example, an Environmental and Energy Study Institute proposal (2010) suggests that in uncertain times, an integrated policy approach for bioenergy might include: inventorying bioenergy resources and markets and developing a long range bioenergy plan; developing sustainable feedstock production guidelines; developing locally appropriate feedstocks and conversion technologies; creating easement programs for sustainable feedstock production; establishing minimum renewable fuel standards; enacting a low carbon fuel standard; promoting interagency cooperation and cooperation with other States; providing tax incentives for producers and retail distributors; and leveraging State resources through Federal and private partnerships.

Given current logistical and technological challenges, developing a mature woody biomass-based energy market would likely depend on some level of government support that includes financial incentives and other regulatory and support policies. Indeed, such policies have emerged in various forms, including research and development, consumption incentives (such as fuel tax reductions), production incentives (such as tax incentives, direct subsidies, and loan guarantees), and mandatory consumption requirements. These and future policies for production, conversion technologies, and markets and distribution can potentially impact the production and commercialization of woody biomass for energy, but might also alter the ecosystem services provided by forests.

Financial incentives might facilitate the increased production and diversion of woody biomass, likely increasing wood demand and adding to the profitability of landowners and those engaged in wood-to-energy conversion. Stand improvement and restoration activities prioritized by States, such as land recovery and cost share programs, might help landowners make the long-term investments. Support for weed and pest management, such as the pine bark beetle prevention program in Virginia, might also increase biomass availability. Best management practices and harvesting guidelines developed especially for bioenergy could restrict wood availability by reducing harvesting impacts through minimum tillage and reduced applications of fertilizers and pesticides; protecting wildlife corridors, riparian zones, and other sensitive areas; and adopting wildlife habitat enhancement measures such as leaving patches of undisturbed areas, promoting certain species mixtures and crop rotations, and retaining quantities of harvest residues, litter, deadwood, snags, and den trees.

Research and technology grants, coupled with subsidies, could help develop current and future wood-for-energy markets. Other financial incentives targeting energy producers might also favor the progress of new conversion technologies and the integration of new technologies with existing ones. Policy efforts geared towards development of gasification techniques or an integrated process with biomass-based electricity generation would likely increase the production of woody biomass-based energy. Technological innovations channeled towards reducing feedstock production costs are significant, as they are likely to spike the demand of wood, luring away some share from traditional forest industries.

A wide array of policy instruments geared towards improving the marketing and distribution of woody biomass-based bioenergy—such as appliance efficiency standards, mandatory utility green power options, and renewable portfolio standards—could play a pivotal role in deciding where the wood–to-energy conversion plants and distribution centers are set up. Because location of infrastructure translates to increased demand for forest biomass, the conditions of nearby forests might change.

Economic and technological uncertainties might influence the impacts that current and future policies have on southern forests. However, the great variety of policies—and the multitude of ways in which the can interact—confounds efforts to predict their potential effects. Policies addressing other environmental and societal benefits associated with forests and wood-to-energy markets might also alter the impacts of bioenergy policies. In particular, emergence of carbon markets could spur further growth in the wood-to-energy industry, but formulating a policy mechanism to realize carbon payments is a huge challenge. For example, under the Carbon Cap and Trade Bill currently in the U.S. Congress, many forest landowners would not qualify for carbon market benefits because they would not get credit for existing levels of carbon sequestration, nor could they meet sequestration permanence standards.

Sustainability Issues

Production of woody biomass for bioenergy can help meet energy goals, but can also stimulate accelerated harvesting, with potentially negative implications for forest ecosystems. Reduction of soil nutrients as well as soil compaction would likely decrease forest productivity. Intensive biomass removal might affect aquatic communities by increasing erosion, runoff, and waterway sedimentation. Intensive forest management might also degrade forest habitat conditions, negatively affecting flora and fauna and reducing biodiversity. Land use changes from natural forest to managed plantations might adversely affect imperiled species in certain locations (see chapter 14). However, changes from agricultural systems to forests might improve habitat conditions. Further, the highgrading of stands generally observed during some timber harvesting might be eliminated with biomass harvesting.

Intensive woody biomass removal might also have some negative implications for community relationships, aesthetics, and public perceptions about forest land as an integral component of southern ecosystems. Potential impacts on forest ecosystems at local and regional levels is most likely to challenge the forestry community to consult new research findings like those summarized below and update existing certification systems with guidelines on how, when, and where woody biomass removals should be conducted:

- Janowiak and Webster (2010) provide a framework that includes adapting management to site conditions, increasing forested land where feasible, using biomass harvests as a restoration tool, evaluating the possibility of fertilization and wood ash recycling, and retaining deadwood and structural heterogeneity for biodiversity.
- Hennenberg and others (2009) suggest creating protected areas that can be used to conserve relevant portions of biodiversity.
- Lal and others (in press) similarly report a set of nine criteria that are necessary to the pursuit of sustainable woody biomass extraction: reforestation and productive capacity, land use change, biodiversity conservation, soil quality and erosion prevention, hydrologic processes, profitability, community benefits, stakeholder participation, and community and human rights.
- Fletcher and others (2009) recommend the following strategies to ensure habitat for biodiversity: reducing harvesting impacts through minimum tillage and reduced fertilizers and pesticides; protecting wildlife corridors, riparian zones, and other sensitive areas; and adopting wildlife habitat enhancement measures such as leaving patches of undisturbed areas, promoting certain species mixtures and crop rotations, and retaining quantities of harvest residues, litter, deadwood, snags, and den trees).

- Multi-stakeholder efforts such as the Roundtable on Sustainable Biofuels and the Global Bioenergy Partnership for biomass harvesting are already underway. The Roundtable on Sustainable Biofuels and Global Bioenergy Partnership are in the process of developing global principles and criteria for developing a set of global, science-based criteria and indicators coupled with field examples and best practices (including benchmarks) for bioenergy sustainability.

In addition to the overall scale of biomass production, the location and methods of woody biomass harvests would affect the health, vitality, and ecological function of southern forests. Existing certification systems such as the Forest Stewardship Council, American Tree Farm System, and Sustainable Forestry Initiative have criteria and indicators to safeguard site productivity, water quality, and biodiversity but some additional indicators may be required for woody biomass harvests. For example, an indicator might be needed to address harvest residues left on site to maintain habitat for small mammals, insects, reptiles, and amphibians. Levels of necessary residues would depend on site-specific conditions, although general guidelines could be formulated at State or Southwide levels. Similarly, erosion-preventing indicators (such as those prohibiting harvests on shallow and nutrient-poor soils) would need to consider specific soil conditions such as depth of soils, nutrient conditions, and regeneration potential.

Biomass harvesting at the levels explored in this chapter could have negative implications for future forest conditions and ecosystem services flowing from southern forests including water (chapter 13) and wildlife/biodiversity (chapter 14). These outcomes depend on the amount and location of harvesting, but perhaps more critically on the management strategies used. The research described above indicates that management systems can be designed to mitigate damages to various ecosystem services. Of course, this requires management planning that addresses management objectives in the context of local conditions. The need for additional best management practices or other guidelines will depend on the rate of development of the bioenergy sector, which is highly uncertain. The acceptability of these approaches would depend on the process of updating best management practices, which would ideally combine public involvement with a science-based process at appropriate scales (Alavalapati and Lal 2009).

Summary

Wood-based energy markets have been proposed as a means to ensure sustainable forests, enhance energy security, promote environmental quality, and realize social benefits. However, several complex issues are influencing the ability to develop these markets in economically efficient, environmentally benign, and socially desirable ways. These issues include biomass availability or supply, market competitiveness and technology development, supportive Federal and State policies, tradeoffs with traditional forest product industries, sustainability, and ecosystem integrity.

This chapter has focused on four interrelated dimensions of bioenergy futures related to southern forests: markets, technologies, policies, and sustainability. Across the various bioenergy scenarios, these new demands would affect the markets for all wood products and lead to price increases for timber products and higher returns to private landowners. The degree to which other wood consumers are impacted would depend on expansion in supply, which in turn depends on intensification of forest management and changes in land use (primarily from agricultural to forestry).

New demands for bioenergy will be determined by expansion of existing technologies—for example, pellets and co-firing with coal—but more critically on the emergence of new technologies that are not yet economically viable. Accelerated technological developments and reduced production costs might be achieved through various policies at Federal and State levels. The sustainability issues surrounding bioenergy are defined by the negative externalities associated with accelerated harvesting in the South. Research indicates that management systems and standards can be designed to protect these values, defining another interface with future policy.

All of these dimensions are fraught with uncertainty. Market futures depend on demands for traditional wood products and on energy prices. Technology development depends on research funding but also on unknowable limits to technical feasibility and the prospect of economic returns. Policy development is highly uncertain and fundamentally engages tradeoffs among energy, environment, community, and other societal objectives. The relationship between harvesting at unprecedented levels and forest ecosystem services is not fully known.

This chapter lays out a broad range of potential developments and management options. Clearly the path to sustainable bioenergy futures will involve enhancing knowledge, monitoring changes, updating expectations, and narrowing the overall uncertainty about future prospects. These issues will likely be the focus of forest assessments for years to come.

Knowledge and Information Gaps

The future of woody bioenergy markets depends on a multitude of factors such as supply and availability of wood biomass; advancements in conversion technologies; improvements in harvesting, collection, storage, densification, preprocessing, and transportation; product prices and elasticities; infrastructure; and productivity increases.

Determining many such factors with confidence was difficult, and our analysis tools were limited. The bioeconomic model that we employed for market analysis calculates harvest levels, related prices, inventory, and acreage as functions of input demands, productivity increases, and various assumed parameters. These relationships are not known with high precision, and the market analysis cannot account for every economic variable and strategic response to the impacts on energy markets. Applying the models to a large number of scenarios provides insights into the range of potential market responses in the future. Improved estimates of the various supply, demand, and production relationships would enhance forecasts of future market developments.

Woody bioenergy production might be more cost competitive under a greenhouse gas reduction strategy that assigns a market value to carbon emissions, in effect allowing social and environmental benefits to be accrued to woody bioenergy. This approach could monetize the benefits gained through greenhouse gas reduction, and those gains could be traded in a carbon market. Although likely to spur further growth in a bioenergy industry, the carbon market approach has yet to formulate a viable mechanism for realizing carbon payments to forest landowners.

The legal definitions of what qualifies as 'forest biomass' under different policy descriptions would generate large variations in forest biomass utilization and therefore require research attention. For example, the Energy Independence Security Act (2007) provides a restricted definition by excluding biomass from public forests and naturally regenerated private forests. Conversely, the 2008 Farm Bill provides a comprehensive definition for forest biomass.

Estimates of the volume of woody material that can used for energy production at secondary wood products manufacturing facilities are imprecise and based on varying assumptions about production facilities and per-unit production potential. Also needing research attention is comprehensive analyses of short rotation woody crops that can be made available for energy use; land use tradeoffs of short rotation woody crops with agriculture, pastures, and forest land; and potential for pine-switchgrass and other agroforestry systems to expand. Productivity gains from changing the geographic range of agriculture and woody biomass feedstocks and improving management is another research area that warrants further attention, as is documenting landowner willingness to participate in forest biomass markets and incorporating this information into woody biomass supply functions.

Additional research is needed to identify sustainability issues surrounding woody biomass utilization for energy. The focus of these concerns ranges from production processes to consumption processes (feedstock production, harvesting, transport, conversion, distribution, consumption, and waste disposal) to job creation and societal benefit distribution. Future research would necessarily focus on the tradeoffs arising from woody biomass diversion for energy use, and the level at which woody bioenergy might become ecologically, economically, and socially undesirable.

Acknowledgments

The authors wish to thank Robert J. Huggett, Jr. and Karen L. Abt, both from Southern Research Station, U.S. Forest Service and Frederick J. Rossi, School of Forest Resources and Conservation, University of Florida for their support and insights. Thanks are also due to Carol Whitlock and Shawna Reid from Southern Research Station, U.S. Forest Service for technical edits and help in preparing GIS maps respectively.

Literature Cited

Abt, R.C.; Abt, K.L. [In press]. Potential impact of bioenergy demand on the sustainability of the southern forest resource. Journal of Sustainable Forestry.

Abt, R.; Abt, K.; Cubbage, F.; Henderson, J. 2010. Effect of policy-based bioenergy demand on southern timber markets: a case study of North Carolina. Biomass and Bioenergy. 34(12): 1679–1686.

Abt, R.C.; Cubbage, F.W.; Abt, K.L. 2009. Projecting southern timber supply for multiple products by subregion. Forest Products Journal. 59(7–8): 7–16.

Abt, R.; Cubbage, F.; Pacheco, G. 2000. Southern forest resource assessment using the Subregional Timber Supply (SRTS) model. Forest Products Journal. 50(4): 25–33.

Adams, D.M.; Alig, R.; Callaway, J.M. [and others]. 1996. The Forest and Agricultural Sector Optimization Model (FASOM): model structure and applications. Res. Pap. PNW–RP–495. Portland, OR: U.S. Department of Agriculture Forest Service, Pacific Northwest Research Station. 60 p.

Aguilar, F.X.; Saunders, A. 2010. Policy instruments promoting wood-to-energy uses in the continental United States. Journal of Forestry. 108(3): 132–140.

Alavalapati, J.; Lal, P. 2009. Woody biomass for energy: an overview of key emerging issues. Virginia Forests. Fall: 4–8.

Alavalapati, J.R.R.; Hodges, A.W.; Lal, P. [and others]. 2009. Southern Bioenergy Roadmap. Research Triangle Park, NC : Southeast Agriculture & Forestry Energy Resources Alliance (SAFER), Southern Growth Polices Board.127p.

Amacher, A.J.; Barrett, R.H.; Moghaddas, J.J.; Stephens, S.L. 2008. Preliminary effects of fire and mechanical fuel treatments on the abundance of small mammals in the mixed-conifer forest of the Sierra Nevada. Forest Ecology and Management. 255(8–9): 3193–3202.

Arnold, C.L. 2000. Land use is the issue, but is land grant the answer? Journal of Extension. 38(6). http://www.joe.org/joe/2000december/comm1.html. [Date accessed: June 15, 2010].

Astrom, M.; Dynesius, M.; Hylander, K.; Nilsson, C. 2005. Effects of slash harvest on bryophytes and vascular plants in southern boreal forest clear-cuts. Journal of Applied Ecology. 42: 1194–1202.

Aulisi, A.; Sauer, A.; Wellington, F. 2007. Trees in the greenhouse: why climate change is transforming the forest products business. World Resources Institute Report. 74 p.

Aust, W.; Blinn, C. 2004. Forestry best management practices for timber harvesting and site preparation in the Eastern United States: an overview of water quality and productivity research during the past 20 years (1982-2002). Water, Air, and Soil Pollution Focus. 4: 5–36.

Beach, R.; Pattanayak, S.; Yang, J. [and others]. 2005. Econometric studies of non-industrial private forest management: a review and synthesis. Forest Economics and Policy. 7: 261–281.

Belanger, R.; Hedden, R.; Lorio, P. 1993. Management strategies to reduce losses from the southern pine beetle. Southern Journal of Applied Forestry. 17: 150–154.

Bies, L. 2006. The biofuels explosion: is green energy good for wildlife? Wildlife Society Bulletin. 34: 1203–1205.

Bingham, M.F.; Prestemon, J.P.; MacNair, D.A.; Abt, R.C. 2003. Market structure in U.S. southern pine roundwood. Journal of Forest Economics. 9: 97–117.

Blottnitz, V. H.; Curran, M.A. 2007. A review of assessments conducted on bio-ethanol as a transportation fuel from a net energy, greenhouse gas, and environmental life-cycle perspectives. Journal of Cleaner Production 15(7): 607-619.

Burger, J.A. 2002. Soil and long-term site productivity values. In: Richardson, J.; Bjorheden, R.; Hakkila, P. [and others], eds. Bioenergy from sustainable forestry: guiding principles and practice. Dordrecht, The Netherlands: Kluwer Academic Publishers: 165–189.

Butler, B.J. 2008. Family forest owners of the United States, 2006. Gen. Tech. Rep. NRS–27. Newtown Square, PA: U.S. Department of Agriculture Forest Service, Northern Research Station. 72 p.

Carter, D.; Langholtz, M.; Schroeder, R. 2007. Biomass resource assessment part I: availability and cost analysis of woody biomass for Gainesville regional utilities. Gainesville, FL: University of Florida, School of Forest Resources and Conservation 122 p.

Cubbage, F.; Hogg, D.; Harris, T., Jr.; Alig, R. 1990. Inventory projection with the Georgia Regional Timber Supply (GRITS) model. Southern Journal of Applied Forestry. 14(3): 124–133.

Database of State Incentives for Renewables and Efficiency. 2010. Incentives/policies for renewables and efficiency. http://www.desireusa.org/summarytables/rrpre.cfm. [Date accessed: June 12 2010].

De La Torre Ugarte, D.; English, B.; Jensen, K. [and others]. 2006. Economic and agricultural impacts of ethanol and biodiesel expansion. Study report by University of Tennessee, Agricultural Economics. http://beag.ag.utk.edu/pp/Ethanol%20UT%20Report%20-%20Final.pdf. [Date accessed: July 14, 2010].

De La Torre Ugarte, D.G.; Ray, D.E. 2000. Biomass and bioenergy applications of the POLYSYS modeling framework. Biomass and Bioenergy. 18(14): 291–308.

De La Torre Ugarte, D.G.; Ray, D.E.; Tiller, K.H. 1998. Using the POLYSYS modeling framework to evaluate environmental impacts in agriculture. In: Robertson, T.; English, B.C.; Alexander, R.R., eds. Evaluating natural resource use in agriculture. Ames, IA: Iowa State University Press: 151–172.

Dwivedi, P.; Bailis, R.; Bush,T.; Marinescu, M. 2011. Quantifying GWI of Wood Pellet Production in the Southern United States and Its Subsequent Utilization for Electricity Production in The Netherlands/Florida. Bioenergy Research. Pp.1-13. doi:10.1007/s12155-010-9111-5

Dwivedi, P.; Alavalapati, J. 2009. Stakeholders' perceptions on forest biomass-based bioenergy development in the Southern U.S. Energy Policy. 37: 1999–2007.

Dwivedi, P.; Alavalapati, J.R.R.; Lal, P. 2009. Cellulosic ethanol production in the United States: conversion technologies, current production status, economics, and emerging developments. Energy for Sustainable Development. 13(3): 174–182.

Ecke, F.; Löfgren, O.; Sörlin, D. 2002. Population dynamics of small mammals in relation to forest age and structural habitat factors in northern Sweden. Journal of Applied Ecology. 39: 781–792.

Energy Independence and Security Act. 2007. H.R. 6. 110th U.S. Congress. http://frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname= 110_cong_bills&docid= f:h6enr.txt.pdf. [Date accessed: June 16, 2010].

Energy Information Administration. 2007. Energy and economic impacts of implementing both a 25-percent renewable portfolio standard and a 25-percent renewable fuel standard by 2025. Report

SR/OIAF/2007–05. http://www.eia.doe.gov/oiaf/servicerpt/eeim/index.html. [Date accessed: July 14, 2010].

Energy Information Administration. 2009. Annual energy outlook. Report DOE/EIA–0383(2009). http://www.eia.doe.gov/oiaf/aeo/pdf/0383(2009).pdf . [Date accessed: January 12, 2010].

Energy Information Administration. 2010a. Annual energy outlook. Report DOE/EIA–0383(2010). http://www.eia.doe.gov/oiaf/aeo/index.html. [Date accessed: June 12].

Energy Information Administration. 2010b. Annual energy outlook. Year-by-year reference case tables (2007-2035). Report DOE/EIA–0383(2010). http://www.eia.doe.gov/oiaf/aeo/aeoref_tab.html. [Date accessed: June 14, 2010].

Energy Information Administration. 2010c. Electric power generation and fuel consumption and stocks monthly time series file. Form EIA–923. http://www.eia.doe.gov/cneaf/electricity/page/eia906_920.html. [Date accessed: June 12, 2010].

Environmental and Energy Study Institute. 2010. Developing and advanced biofuels industry: State policy options and uncertain times. http://www.eesi.org/021610_state_biofuel_paper. [Date accessed: June 15].

Eriksson, E. ;Gillespie, A.; Gustavsson, L. [and others]. 2007. Integrated carbon analysis of forest management practices and wood substitution. Canadian Journal of Forest Research 37(3): 671-681.

Faaij, A.; Domac, J. 2006. Emerging international bioenergy markets and opportunities for socio-economic development. Energy for Sustainable Development. 1: 7–19.

Fletcher, R.; Alavalapati, J.; Evans, J.; Matta, J. 2009. Impacts of bioenergy production on the conservation of wildlife habitat. Wildlife Habitat Policy Research Program. Final report. http://ncseonline.org/00/batch/WHPRP/2008%20Final%20Reports/2E%20Fletcher_et%20al_WHPRP%20final%20report.pdf. [Date accessed: June 26, 2010].

Fletcher, R.; Robertson, B.A.; Evans, J. [and others]. 2011. Biodiversity conservation in the era of biofuels: risks and opportunities. Frontiers in Ecology and the Environment. 9: 161–168. [doi:10.1890/090091].

Fox, T.; Jokela, E.; Allen, H. 2007. The development of pine plantation silviculture in the Southern United States. Journal of Forestry. October/November: 337–347.

Fritsche, U.R.; Hunecke, K.; Schulze, F.; Wiegman. K. 2006. Sustainability standards for bioenergy. Darmstadt, Germany: WWF Germany, Oeko-Institut. www.wwf.de/fileadmin/fm-wwf/pdf_neu/Sustainability_Standards_for_Bioenergy.pdf. [Date accessed: July 6, 2010].

Galbe, M.; Zacchi, G. 2002. A review of the production of ethanol from softwood. Applied Microbiolgy Biotechnology. 59: 618–628.

Galik, C.; Abt, R.; Wu, Y. 2009. Forest biomass supply in the Southeastern United States- implications for industrial roundwood and bioenergy production. Journal of Forestry. 107(2): 69–77.

Gan, J.; Mayfield, C. 2007a. Benefits to Landowners from Forest Biomass/Bioenergy Production. In: Hubbard, W.; L. Biles; C. Mayfield; S. Ashton (Eds.). 2007. Sustainable Forestry for Bioenergy and Bio-based Products: Trainers Curriculum Notebook. Athens, GA: Southern Forest Research Partnership, Inc. pp 225-228.

Gan, J.; Mayfield, C. 2007b. The Economics of Forest Biomass Production and Use. In: Hubbard, W.; L. Biles; C. Mayfield; S. Ashton (Eds.). 2007. Sustainable Forestry for Bioenergy and Bio-based Products: Trainers Curriculum Notebook. Athens, GA: Southern Forest Research Partnership, Inc. pp 213-216.

Gan, J.; Smith, C.T. 2006a. A comparative analysis of woody biomass and coal for electricity generation under various CO2 emissions reductions and taxes. Biomass and Bioenergy. 30(4): 296-303.

Gan, J.; Smith, C.T. 2006b. Availability of logging residues and potential for electricity production and carbon displacement in the USA. Biomass and Bioenergy 30(12): 1011–1020.

Greene, J.L.; Daniels, S.; Kilgore, M.A. [and others]. 2005. Existing and potential incentives for practicing sustainable forestry on non-industrial private forest lands. Final report to the National Commission on Science for Sustainable Forestry. http://www.srs.fs.usda.gov/econ/data/forestincentives/ncssf-c2-final-report.pdf. [Date accessed: July 15, 2010].

Gorte, R.W.; Ramseur, J.L. 2008. Forest carbon markets: potential and drawbacks. Report prepared by CRS for Congress. Washington, DC: CRS RL34560. http://www.nationalaglawcenter.org/assets/crs/RL34560.pdf. [Date accessed: July 16, 2010].

Grigal, D. 2000. Effects of extensive forest management on soil productivity. Forest Ecology and Management. 138: 167–185.

Guo, Z.; Sun, C.; Grebner, D.Q. 2007. Utilization of forest derived biomass for energy production in the U.S.A.: status, challenges, and public policies. International Forestry Review. 9(3): 748–758.

Gustavsson, L.; Holmberg, J.; Dornburg, V. [and others]. Using biomass for climate change mitigation and oil reduction. Energy Policy 35(11): 5671-5691.

Haines, A.L. 2002. Blended teaching: land use planning education in Wisconsin and lessons learned. Journal of Extension. 40(5). http://www.joe.org/joe/2002october/iw2.shtml. [Date accessed: June 12, 2010].

Hennenberg, K.; Dragisic, C.; Hewson, J. [and others]. 2009. The power of bioenergy-related standards to protect biodiversity. Conservation Biology. 24(2): 412–423.

Hill, J.; Nelson, E.; Tilman, D. [and others]. 2006. Environmental, economic, and energetic costs and benefits of biodiesel and ethanol biofuels. Proceedings of the National Academy of Sciences. 103(30): 11,206–11,210.

Hope, G. 2007. Changes in soil properties, tree growth, and nutrition over a period of 10 years after stump removal and scarification on moderately coarse soils in interior British Columbia. Forest Ecology Management. 242(2–3): 625–635.

Huang, M.Y. 2010. Regional impacts of bioenergy policies in the Southeastern United States: a computable general equilibrium analysis. Dissertation submitted to University of Florida. http://purl.fcla.edu/fcla/etd/UFE0041091. [Date accessed: June 26].

Hughes, E. 2000. Biomass co-firing: economics, policy and opportunities. Biomass and Bioenergy. 19: 457–465.

Humphrey, J.; Davey, S.; Peace, A. [and others]. 2002. Lichens and bryophyte communities of planted and seminatural forests in Britain: the influence of site type, stand structure and deadwood. Biology Conservation. 107(2): 165–180.

Jackson, S.; Rials, T.; Taylor, A.M. [and others]. 2010. Wood to energy: a state of the science and technology report. University of Tennessee and U.S. Endowment for Forestry and Communities Report. Tennessee: The University of Tennessee 56 p.

Jacobson, M.G.; Greene, J.L.; Straka, T.J. [and others]. 2009. Influence and effectiveness of financial incentive programs in promoting sustainable forestry in the South. Northern Journal of Applied Forestry. 33(1): 35–41.

Janowiak, M.; Webster, C. 2010. Promoting ecological sustainability in woody biomass harvesting. Journal of Forestry. 108(1): 16–23.

Johnson, T.G.; Bentley, J.W.; Howell, M. 2009. The South's timber industry—an assessment of timber product output and use, 2007. Resour. Bull. SRS–164. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 52 p.

Jonsell, M. 2007. Effects on biodiversity of forest fuel extraction, governed by processes working on a large scale. Biomass and Bioenergy. 31(10): 726–732.

Joshi, S.; Arano, K.G. 2009. Determinants of private forest management decisions: a study on West Virginia NIPF landowners. Forest Policy and Economics. 11(2): 118–125.

Kilgore, M.A.; Greene, J.L.; Jacobson, M.G. [and others]. 2007. The influence of financial incentive programs in promoting sustainable forestry on the nation's family forests. Journal of Forestry. June: 184–191.

Kumarappan, S.; Joshi, S.; MacLean, H. 2009. Biomass supply for biofuel production: estimates for the United States and Canada, BioResources. 4(3): 1070–1087.

Lal, P.; Alavalapati, J.; Marinescu, M. [and others]. 2009. Sustainability indicators for woody biomass harvesting. The future of wood bioenergy in the United States: defining sustainability, status, trends and outlooks for regional development volume by Pinchot Institute for Conservation. http://www.pinchot.org/bioenergy_paper. [Date accessed: July 12, 2010].

Lal, P.; Alavalapati, J.; Marinescu, M. [and others]. [In press]. Developing sustainability indicators for woody biomass harvesting in the United States. Journal of Sustainable Forestry.

Liao, X.; Zhang, Y. 2008. An econometric analysis of softwood production in the U.S. South: a comparison of industrial and nonindustrial forest ownerships. Forest Products Journal. 58(11): 69–74.

Lucier, A. 2010. Fatal Flaw in Manomet’s Biomass Study**.** The Forestry Source, September 2010. p 4.

Mayfield, C.A.; Foster, C.D.; Smith, C.T. [and others]. 2008. Opportunities, barriers, and strategies for forest bioenergy and bio-based product development in the Southern United States. Biomass & Bioenergy. 31(9): 631–637.

Mckendry, P. 2002. Energy production from biomass (part 2): conversion technologies. Bioresource Technology. 83(1): 47–54.

Mendell, B.; Lang, A.H.; Tydor,T. 2010. Economic and Regional Impact Analysis of the Treatment of Biomass Energy Under the EPA Greenhouse Gas Tailoring Rule. Commissioned by National Alliance of Forest Owners. Athens, GA: Forisk Consulting. 32p.

Mercer, E.: Lal, P.; Alavalapati, J. 2011. Competitiveness of Carbon Offset Projects on Nonindustrial Private Forest Lands in the United States. In: Alig, R.J. (Ed.). Economic modeling of effects of climate change on the forest sector and mitigation options: a compendium of briefing papers. Gen. Tech. Rep. PNW-GTR. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 119–160.

Milbrandt, A. 2005. A geographic perspective on the current biomass resource availability in the United States. Tech. Rep. NREL/TP–560–39181. http://www.nrel.gov/docs/fy06osti/39181.pdf. [Date accessed: June 16, 2010].

Neary, D.; Zieroth, E. 2007. Forest bioenergy system to reduce the hazard of wildfires: White Mountains, Arizona. Biomass and Bioenergy. 31: 638–645.

Neary, D.G. 2002. Hydrologic values. In: Richardson, J.; Bjorheden, R.; Hakkila, P. [and others], eds. Bioenergy from sustainable forestry: guiding principles and practice. Dordrecht, The Netherlands: Kluwer Academic Publishers: 190–215.

Nesbit, T.; Alavalapati, J.R.R.; Dwivedi, P.; Marinescu, M. 2011. Economics of ethanol production using feedstock from slash pine (*Pinus elliottii*) plantations in the Southern United States. Southern Journal of Applied Forestry 35(2):61-66.

Oak Ridge National Laboratory. 2008. Bioenergy Conversion Factors. Available online at bioenergy.ornl.gov/papers/misc/energy_conv.html. [Date accessed: June 10, 2010].

O'Laughlin, J. 2010. Accounting for Greenhouse Gas Emissions from Wood Bioenergy: Response to the U.S. Environmental Protection Agency's Call for Information, Including Partial Review of the Manomet Center for Conservation Sciences' Biomass Sustainability and Carbon Policy Study. Report No. 31. Moscow, ID: Policy Analysis Group, College of Natural Resources. University of Idaho. p58.

Oklahoma Department Of Agriculture, Food, And Forestry . 2008. Southern Pine Beetle Threat Draws Cost-Share FUNDS. 2800 North Lincoln Blvd Oklahoma City OK 73105-4298. http://www.ok.gov/~okag/forms/forestry/pinebeetle.pdf. [Date accessed: April 16, 2011].

Pattanayak, S.; Murray, B.; Abt, R. 2002. How joint is joint forest production? An econometric analysis of timber supply conditional on endogenous amenity values. Forest Science. 48(3): 479–491.

Pattanayak, S.K.; Abt, R.C.; Sommer, A.J. [and others]. 2005. Forest forecasts: does individual heterogeneity matter for market and forest landscape outcomes? Forest Policy and Economics. 6(3–4): 243–260.

Pellet Fuels Institute. 2010. Homepage. http://www.pelletheat.org/3/residential/ fuelAvailability.cfm. [Date accessed: June 16, 2010].

Peng, C.; Jiang, H.; Apps, M.J.; Zhang, Y. 2002. Effects of harvesting regimes on carbon and nitrogen dynamics of boreal forests in central Canada: a process model simulation. Ecological Modeling. 155: 177–189.

Perlack, R.D.; Wright, L.L.; Turhollow, A.F. [and others]. 2005. Biomass as feedstock for a bioenergy and bioproducts industry: the technical feasibility of a billion-ton annual supply. DOE/GO–102995–2135. Joint report by U.S. Department of Agriculture and Department of Energy. Oak Ridge, Tennessee: Oak Ridge National Laboratory. 58p.

Prestemon, J.P.; Abt, R.C. 2002. Timber products supply and demand. In: Wear, D.; Greis, J., eds. Southern Forest Resource Assessment. Gen. Tech. Rep. SRS–53. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station: 299–326.

Reijnders, L. 2006. Conditions for the sustainability of biomass based fuel use. Energy Policy. 34(7): 863–876.

Renewable Fuels Association. 2010. Ethanol industry outlook. http://www.ethanolrfa.org/pages/annual-industry-outlook. [Date accessed: June 16].

Rossi, F.J.; Carter, D.R.; Abt, R.C. 2010. Woody biomass for electricity generation in Florida: bioeconomic impacts under a proposed Renewable Portfolio Standard (RPS) mandate. Final report prepared for Florida Department of Agriculture and Consumer Services, Division of Forestry. Gainesville, FL: School of Forest Resources and Conservation. 98p.

Sample, V.A. 2009. Ensuring sustainability in the development of wood-based bioenergy in the US South. http://www.pinchot.org/gp/SouthRegionalMeeting. [Date accessed: July 25, 2010].

Schaberg, R.H.; Aruna, P.B.; Cubbage, F.W. [and others]. 2005. Economic and ecological impacts of wood chip production in North Carolina: an integrated assessment and subsequent applications. Journal of Forest Policy and Economics. 7(2): 157–174.

Scott, D.; Dean. T. 2006. Energy trade-offs between intensive biomass utilization, site productivity loss, and ameliorative treatments in loblolly pine plantations. Biomass & Bioenergy. 30: 1001–1010.

Searchinger, T.; Heimlich, R.; Houghton, R. A. [and others]. 2008. Use of U.S. Croplands for Biofuels Increases Greenhouse Gases through Emissions from Land Use Change. Science, 319 (5867): 1238 -1240.

Sendek, P.E.; Abt, R.C.; Turner, R.J. 2003. Timber supply projections for northern New England and New York: integrating a market perspective. Northern Journal of Applied Forestry. 20(4): 175–185.

Shrum, T. 2007. Greenhouse Gas Emissions: Policy and Economics. Report Prepared for the Kansas Energy Council . Topeka, Kansas: Kansas Energy Council. August 3, 2007 . 78 p. http://kec.kansas.gov/reports/GHG_Review_FINAL.pdf [Date accessed: July 22, 2010].

Siry, J.P.; Cubbage, F.; Malmquist, A. 2001. Potential impact of increased management intensities on planted pine growth and yield and timber supply modeling in the South. Forest Products Journal. 51(3): 42–48.

Siry, J.P.; Robison, D.J.; Cubbage, F.W. 2004. Economic returns model for silvicultural investments in young hardwood stands. Southern Journal of Applied Forestry. 28: 179–184.

Smith, T.; lattimore, B. 2008. Potential Environmental Impacts of Bioenergy Harvesting on Biodiversity. Forest Encyclopedia Network. Encyclopedia ID: t450. Last Modified: 2008-11-14 . http://www.threats.forestencyclopedia.net/t/t450/?searchterm=mitigating[Date accessed: April 22, 2011].

Speight, M. 1997. Forest pests in the tropics: current status and future threats. In: Watt, A.; Stork, N.; Hunter, M., eds. Forests and insects. London: Chapman and Hall. 406 p.

Spelter, H.; Toth, D. 2009. North America’s wood pellet sector. Res. Pap. FPL–RP–656. Madison, WI: U.S. Department of Agriculture Forest Service, Forest Products Laboratory. 21 p.

Stupak, I.; Asikainen, A.; Jonsell, M. [and others]. 2007. Sustainable utilization of forest biomass for energy - possibilities and problems: policy, legislation, certification, and recommendations and guidelines in the Nordic, Baltic, and other European countries. Biomass & Bioenergy. 31(10): 666–684.

Susaeta, A.; Alavalapati J.; Carter, D. 2009. Modeling impacts of bioenergy markets on nonindustrial private forest management in the Southeastern United States. Natural Resource Modeling. 22(3): 345–369.

Susaeta, A.; Alavalapati, J.; Lal, P.; Matta, J. 2010. Assessing public preferences for forest biomass based energy in the Southern United States. Environmental Management. 45(4): 697–710.

Thiffault, E.; Paré, D.; Bélanger, N. [and others]. 2006. Harvesting intensity at clear-felling in the boreal forest: impact on soil and foliar nutrient status. Soil Science Society of American Journal. 70: 691–701.

Thiffault, E.; Pare, D.; Brais, S.; Titus, B. 2010. Intensive biomass removals and site productivity in Canada: a review of relevant issues. Forestry Chronicle. 86(1): 36–42.

Thor, M.; Stenlid, J. 2005. *Heterobasidion annosum* infection of *Picea abies* following manual or mechanized stump treatment. Scandinavian Journal of Forest Research. 20: 154–164.

United States Forest Service. 2005. A strategic assessment of forest biomass and fuel reduction treatments in Western states. RMRS-GTR-149. Fort Collins, CO: 17. U. S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 17p.

Van Loo, S.; Koppejan, J. 2008. The Handbook of Biomass Combustion and Cofiring. London, UK: Earthscan. 442 pp.

Walmsley, J.; Godbold, D. 2010. Stump harvesting for bioenergy – a review of the environmental impacts. Forestry. 83(1): 17–38.

Walsh, M.E. 2008. U.S. cellulosic biomass feedstock supplies and distribution. www.ageconsearch.umn.edu/bitstream/7625/2/U.S.%20Biomass%20Supplies.pdf. [Date accessed: July 5, 2010].

Wear, D.; Abt, R.; Alavalapati, J. [and others]. 2010. The South's outlook for sustainable forest bioenergy and biofuels production. The Pinchot Institute Report. 20 p.

Wear, D.; Greis, J.; Walters, N. 2009. The Southern Forest Futures Project: using public input to define the issues. Gen. Tech. Rep. SRS–115. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 17 p.

Wiltsee, G. 1998. Urban wood waste resource assessment. Golden, CO: National Renewable Energy Laboratory. 177 p.

Zhu, J.Y.; Pan, X.J. 2010. Woody biomass pretreatment for cellulosic ethanol production: technology and energy consumption evaluation. Bioresource Technology. 100(13): 4992–5002.

Appendix A: Total Wood Demand for Energy Estimation

Estimation of the woody biomass required for electricity production began with Energy Information Administration (2010a) data on electricity generation for sales, in billion kilowatt-hours (KWH), for different electricity grids catering to customers in the Southern region. The grid-based sales data is available only until 2035, but we extrapolated the data to extend it to 2050 by using average growth rate of the five preceding years. Determining the amount of the consumed within the 13 Southern states is challenging because the electric grid networks do not track the volume of power flowing to or from individual areas, nor do they break out the electricity sales information by state jurisdictions (Pers. communication R. J. Robertson, Manager, Customer Relations, Southwest Power Pool on May 20, 2010, and Teresa Glaze, Data Analyst, SERC Reliability Corporation on May, 21 2010).

We approached this problem by assuming that a fixed percentage of individual grid electricity caters to the South (similar to studies such as Galik and others 2009, Rossi and others 2010). The percentage allocations of total sales within the South are based on expert opinions and the electricity demand storyline is not expected to drastically change, with little alterations in percentages.

The Florida Reliability Coordinating Council and Electric Reliability Council of Texas Grids serve customers within the Southern region only, so we assumed that 100% of their sales are within the South. Other electric grids, on the other hand, cater to customers outside the Southern region as well. The Southeast Reliability Corporation serves all of the states of Missouri, Alabama, Tennessee, North Carolina, South Carolina, Georgia, Mississippi, and portions of Iowa, Illinois, Kentucky, Virginia, Oklahoma, Arkansas, Louisiana, Texas and Florida. To account for supply to non-southern states – the whole of Missouri and portions of Iowa and Illinois – 16 percent of the total electricity supplied by the grid was subtracted. The Southwest Power Pool serves all of the state of Kansas, and portions of New Mexico, Texas, Oklahoma, Arkansas, and Louisiana, Missouri and Nebraska. Here, 36 percent of the total electricity of the grid is assumed to cater to Southern states - Texas, Oklahoma, Arkansas, and Louisiana and the other 64 percent was subtracted. An East Central Area Reliability Coordination Agreement state, now merged into Reliability First Corporation, serves portions of the Southern states of Kentucky and Virginia. Here, 18 percent of the total electricity is assumed to flow into Kentucky and Virginia, while the other 82 percent is netted out. Western Texas also receives some electricity from the Western Electricity Grid. Rather than apportioning part of the Western Grid supply, we inflated the electricity supply of the major supplier in the state Electric Reliability Council of Texas by 6 percent.

Using the percentage apportioning described above, we scaled down the total annual electricity sales outlined in Energy Information Administration (2010a) reference case scenario for the Southern region. Once we determined the total annual sales of electricity, we derived the share of woody biomass-based electricity. The same source of data Energy Information Administration (2010a) supplies values, also expressed in billion kWh, for the amounts of renewable energy for different electricity grids. These data are broken down by the type of renewable energy, listed as conventional hydroelectric, geothermal, wood and other biomass, biogenic municipal waste, wind, photovoltaic, and solar thermal sources but exclude ethanol, net electricity imports, and non-marketed renewable energy consumption for geothermal heat pumps, buildings photovoltaic systems, and solar thermal hot water heaters. We scaled down the renewable energy and wood and other biomass data using the percentage factor used before for the total electricity sales for the Southern region. Using total electricity demanded, total renewable electricity, and total woody and other biomass-based electricity data, we derived the share of renewables in the total electricity portfolio of the region as well as the share of wood-based biomass electricity within the renewables. Following Galik and others (2009), we assumed that energy from wood and other biomass sources outlined in Energy Information Administration (2010a) is completely woody in nature.

The woody biomass demand specified as electricity in billion KWH was converted to woody biomass in thermal energy terms of trillion BTUs. Following Rossi and others (2010), we used an effective conversion factor of 13,648 BTU per KWH, which is the standard electricity to thermal energy conversion factor (3,412 BTU per KWH) at a 25 percent level of efficiency. This is congruent to Wiltsee (2000) study of biomass-fuelled power plants, which reported typical higher heating value to be approximately 14,000 Btu per KWH (24.4 percent efficiency).

To account for conversion efficiency increases due to factors such as increased use of co-firing with coal in the future, replacing older combustion steam turbines with gasification combined cycle plants, and technological advances to all types of biomass power plants, we assumed a gradual increase in thermal efficiency after 2020, reaching a maximum of 40 percent in 2050. Next we converted woody biomass in BTUs to mass in green tons by using a conversion factor of 8,600,000 BTU per green ton outlined by United States Forest Service (USFS) (2004) green wood (50 percent moisture content). Next we needed to allocate how much of the total biomass used for energy is sourced from softwoods and hardwoods. This is challenging, as weight-to-volume conversion factors vary with stem size and specific gravity of species. Galik et al (2009) estimated conversion factors for trees of average diameters based on Timber Mart-South 2007 data. We followed their conversion factors --34.44 green tons per thousand cubic feet for softwood and 35.98 green tons per thousand cubic feet for hardwood.

Estimating Wood Based Liquid Fuels Demand

Estimation of the woody biomass required for liquid fuels production began with projected Enenrgy Information Administration (2010a) Renewable Energy Consumption by Sector and Source tables. We used these tables to determine percentage share of cellulosic ethanol with respect to the total domestic ethanol production. While extrapolating ethanol production from 2036-2050, we pegged the corn and starch ethanol production value at the 2035 level and assumed that increased ethanol production will come from cellulosic sources alone. This is in sync with current Renewable Fuel Standard target of pegging corn and starch ethanol production at a fixed level and allows for increase in ethanol production through cellulosic sources alone.[3]

We estimated total domestic cellulosic ethanol production (in million barrels per day) based on percentage share data provided by Energy Information Administration (2010a) Liquid Fuels Supply and Disposition Tables. We added data for other biomass-derived liquids such as pyrolysis oils, biomass-derived Fischer-Tropsch liquids, and renewable feedstocks used for the production of green diesel and gasoline, gathered from the same source, to get total liquid fuels that can be produced from wood or other cellulosic sources. We scaled down cellulosic liquid fuels demand at the national level to Southern levels based on the assumption that 55 percent of the national demand will be met by 13 Southern States. Since wood is a high-volume low-value product, transportation costs limit its transport to conversion plants far from harvested areas. In this light, the figure of 55 percent is conservative, as 57 percent of wood harvesting occurs in the South (Hanson et al. 2010).

A suite of feedstocks (including wood, paper and pulp liquors, algae, switch grass, agricultural residue, etc.) can be used to produce cellulosic ethanol or other bio-oils. As the future of liquid fuel from biomass sources is uncertain and we do not know what percentage of total cellulosic ethanol and other bio-oils can be met through wood sources, we assumed that 30percent of the total cellulosic fuels and bio-oils are woody in nature. We converted barrel per day demand to gallons per day using conversion

[3] The EIA (2010a) projections assume that the Renewable Fuel Standard target of cellulosic ethanol will not be met by 2022.

factors outlined in Oak Ridge National Laboratory (2008) whereby 1 barrel equals 42 gallons. We converted daily consumption data to annual levels by multiplying by a factor of 365.242. We converted gallons into green ton of wood using ethanol yield calculator (http://www1.eere.energy.gov/biomass/ethanol_yield_calculator.html) that outlines that 40.75 gallons and 50.4 gallons of ethanol and bio-oils can be produced per green ton of softwood and hardwood respectively. We further converted the wood demand in thousand cubic feet by using volume-to-weight conversion factors used by Galik and others (2009).

Estimating Wood Pellet Demand

The wood pellet industry in the country is already established, in contrast to the industry focus towards wood electricity or wood fuels (Alavalapati and Lal 2009, Spelter and Toth 2009). However, the wood pellet industry in US, to a large extent, is being driven by European demand (Gold 2009). This along with the use of wood pellets for domestic heating rather than grid electricity might result in incomplete accounting in (2010) where renewable electricity productions are estimated in terms of electricity grid sales. This prompted us to account for wood pellet demand separate than wood based electricity demand. Spelter and Toth (2009) estimated pellet plant capacity for the South to be 1.85 million green tons in 2009. Based on 66 percent average efficiency of operation for U.S. based plants outlined in the same report, we estimated the demand for wood for pellets in the Southern region to be 1.22 million tons. As many states within the country are pushing for renewables, domestic demand is likely to increase in future. To account for expected demand increase in future, we assumed 0.5 percent annual increase in the capacity of pellet plants from 2011 onwards. The capacity utilization of pellet plants in the country is lower as compared to countries like Canada which have utilization efficiency of 81 percent. Spelter and Toth (2009) attributed this to reasons such as newer plants, normal start-up problems, and limits on fiber availability. However, they also say that as plants become older, the capacity utilization is expected to increase. To account for technological advancements, we assumed that overall capacity utilization increases by one percent per year from 2015 until it reaches 85 percent. We added wood demand for electricity, liquid fuels, and pellets so estimated to calculate total woody (TW) biomass demand.

Harvest Residue and Urban Wood Waste Utilization

The method used to calculate the HR and that urban wood waste can be used for energy production has been elucidated in this section. Current literature (Perlack and others 2005, Galik and others 2009, Energy Information Administration 2010a) indicates that harvesting residues , discarded tree tops and limbs generated during the harvesting process, currently being left on the ground can be used as woody biomass-based energy feedstocks. Recent analysis (Galik and others 2009, Rossi and others 2010) suggests that harvesting residues might be utilized before diverting merchantable timber for energy production. Rossi and others (2010) also argue that woody biomass demand for energy production need to be scaled down further to account for urban wood waste that can be diverted for energy production. Since these wood sources might be used before diverting merchantable timber (Rossi and others 2010, Perlack and others 2005), we reduced urban wood waste from the total woody biomass consumption figures. This essentially gives us the merchantable timber that will be required for energy production. Note that the harvesting residues from additional harvest were handled endogenously. The model calculates softwood and hardwood harvest residues along with the merchantable timber that can be harvested in a particular year. For each year, the harvesting residues that can be made available is estimated along with the harvest levels of softwood and hardwood pulpwood and sawtimber. It doesn't deal with urban wood waste so we netted out urban wood waste from total woody biomass consumption and fed into the model to get results.

The harvest residue that can be used for energy production depends on total harvest as well as residue utilization factor (percentage of harvest residue that can be converted to energy). Increased harvesting efficiency can impact viability of forest residues in future (Grushecky and others 2007). Rather than having a constant harvesting residue utilization factor (40 percent for Walsh and others 2008, 45 percent for Rossi and others 2010, 50 percent for Galik and others 2009), we assume that the utilization factor follows an increasing trend—45 percent in 2010 that increases to 67 percent in 2025 and remains pegged at this level till the terminal year (2050). We believe that estimate of technical recovery that progressively increases through time better characterizes harvest efficiency and technology improvements occurring along with the development of a forest residues market. The forest residue removal must also consider adverse impacts on site productivity and biodiversity (see, e.g. Lal and others 2009). In the US, some state guidelines encourage the retention of potion forest residues on sites, through their biomass harvesting guidelines. The proportion of residues left on ground suggested by different state guidelines ranges from 10-33 percent (Lal and others in press). Noting the maximum percentage of residue retention at the site suggested by state biomass harvesting guidelines, we assume that not more than 67 percent of harvest residues can be removed and utilized for energy production.

Total harvest residues is handled endogenously by modified SRTS model. The modified SRTS uses residual factors, specified in Johnson and others (2009), to estimate softwood and hardwood harvest residues produced for different woody biomass consumption scenarios. For the survey units in this study, the harvesting residual factors for softwood range from 0.049 to 0.161 (per cubic foot of removals) for growing stock, and 0.091 and 0.357 for non-growing stock. For hardwoods, the residual factors range from 0.106 to 0.247 for growing stock and 0.1945 and 0.3783 for non-growing stock.

Wiltsee (1998) estimated that 0.203 green tons per year of urban wood waste is produced per capita. We used this per capita figure along with the yearly estimates of future population of the Southern States to obtain the annual amount of urban wood waste generated in the region. The future population figures were obtained from the US Census Bureau States Interim Population Projections by Age and Sex data sets[4]. Carter and others (2007) suggest that we need to scale down the per capita urban wood waste estimation by a utilization factor as not all urban wood waste can be diverted for energy use. We used the utilization factor suggested in the same study (60percent) to calculate the total urban wood waste that can be diverted for energy use. For allocating total urban wood waste that can be converted to energy into four products, we assumed that the UWW product share follows the trend of total woody biomass based energy demand (e.g. if other non sawtimber is X% of total woody biomass consumption requirement in the particular year then X% of urban wood waste is assumed to come from other).

Allocating Merchantable Timber into Four Products

While allocating percentage share within a species group, we allocated woody biomass requirement net of HR added only to the pulpwood market, as many researchers suggest that sawtimber and other higher-value forest resources might be too expensive to be used for bioenergy production (e.g., Hazel 2006). The non-sawtimber-based feedstock preference can also be observed in a recent study by Rossi et al (2010) in Florida whereby they assumed that 88% of the total timber diverted for energy comes

[4] http://www.census.gov/population/www/projections/projectionsagesex.html. The population projections are extrapolated till 2050.

from non-sawtimber sources. However, Perlack et al. (2005) outline the possibility that high oil prices and low timber prices may create conditions whereby pulpwood or even small sawtimber resources could be used for bioenergy purposes.[5]

For this study we selected four products defined by broad species type (hardwood and softwood) and diameter range. We refer to these four categories as: Softwood Non-sawtimber (SWNS); Softwood sawtimber (SWS); Hardwood Non-sawtimber (HWNS); and Hardwood sawtimber (HWS). The SRTS model utilizes diameter distributions for each sub-region, owner, management type, and age class to calculate product removals and inventory volumes by age class. We modified age-class in SRTS from a five-year period to annual levels so that the supply response could be consistent with consumption data. Furthermore, the user must also specify a cull factor and diameter range which determines how much volume (in each product category) contributes to non-saw timber. We used the cull factor outlined in Abt et al. (2009, 2010) and demarcated saw and non-saw based on FIA diameter at breast height (dbh) definitions. The dbh range is between 5" to 8.9" for SWNS; between 5" to 10.9" for HWNS; more than 9.0" for SWS; and 11.0" or more for HWS. Trees with less than 5" dbh are considered as saplings.

References

Gold, R. 2009. Wood pellets catching fire as a renewable energy source. Wall Street Journal. July 7, 2009. http://online.wsj.com/article/SB224691728110402383. [Date accessed: July 12, 2010].

[5] We assumed that non-sawtimber wood will be used for energy production earlier than high value sawtimber. However, at higher level of woody biomass consumption, we can determine how much of the woody biomass requirement can't be met by non-sawtimber wood. We posit that this extra requirement of biomass (over and above the harvest levels of species depicted by the model runs) is sourced by displacing softwoods and hardwoods saw-timber from forest industries.

Grushecky, S. T.; Wang, J.; McGill, D. W. 2007. Influence of site characteristics and costs of extraction and trucking on logging residue utilization in southern West Virginia. Forest Products Journal, . 57(7/8): 63–-67.

Hanson, C.; Yonavjak, L.; Caitlin Clarke, C. [and others] 2010. Southern forests for the future. Washington, DC: World Resources Institute. 88p.

Hazel, D. 2006. How will our forests be impacted by a woody biomass energy market? Presentation given at Energy from Wood: Exploring the Issues and Impacts for North Carolina, Raleigh, NC, March 13-14, 2006. http://www.ces.ncsu.edu/nreos/forest/feop/Agenda2006/energy/presentations/hazel.pdf[Date accessed: July 12, 2010].

Timber Mart-South. 2007. Timber Mart-South market news quarterly. http://www.tmart-south.com/tmart/news.htm. [Date accessed: May 20, 2010].

U.S. Department of Agriculture Forest Service. 1988. The South's fourth forest: alternatives for the future. For. Res. Rep. 24. Washington, DC. 512 p.

U.S. Department of Agriculture Forest Service, Forest Products Laboratory. 2004. Fuel value calculator. TechLine Publ. WOE–3. http://www.fpl.fs.fed.us/documnts/techline/fuel-value-calculator.pdf. [Date accessed: June 14, 2010].

Wiltsee, G. 2000. Lessons learned from existing biomass power plants. NREL/SR–-570–-26946. Golden, CO: National Renewable Energy Laboratory. Golden, CO. http://www.nrel.gov/docs/fy00osti/26946.pdf . [Date accessed: June 26, 2010].June 26, 2010.

Tables

Table 10-1—Allocation of woody biomass for energy production under woody biomass consumption scenarios by 2050

Woody biomass consumption scenario	Electricity	Liquid fuels	Wood pellets
Low	Based on Energy Information Administration (2010b) projections	Provides 30 percent of renewable energy sources	Based on Spelter and Toth (2009)
Medium	Increases to 20 percent of renewable energy sources by 2050, with share of total electricity sources remaining the same as in the low-consumption scenario	Increases to 50 percent of renewable energy sources by 2050, with 30 percent of total liquid energy coming from woody sources	Increases by 25 percent for the period 2015-2050
High	Increases to 40 percent of renewable energy sources by 2050, with 20 percent of total electricity coming from woody sources	Increases to 50 percent of renewable energy sources by 2050, with 40 percent of total liquid fuel coming from woody sources	Increases by 50 percent for the period 2015-2050

Table 10-2—Simulations of supply responses when woody biofuels at three consumption levels are matched with four productivity strategies, 2050

Woody biomass consumption scenario	Productivity strategy	Details
Medium	Only improve pine plantation productivity	Productivity of pine plantations doubles; no change in other forest management types
Medium	Improve productivity on all management types	Productivity of pine plantations doubles by 2050 and productivity of other forest management types increases by 50 percent
High	Only improve pine plantation productivity	Productivity of pine plantations doubles; no change in other forest management types
High	Improve productivity on all management types	Productivity of pine plantations doubles and productivity of other forest management types increases by 50 percent
Short rotation woody crops woody	Improve productivity on all management types and expand short rotation woody crops	Short rotation woody crops growing on agricultural or pasture land offset 10 percent of wood energy demand; productivity of pine plantations doubles and productivity of other forest management types increases by 25 percent
High	Low productivity	Productivity of pine plantations increases by 50 percent and productivity of other forest management types increases by 25 percent

Table 10-3—Modified Subregional Timber Supply Model assumptions

Assumption	Scenario/Strategies	Details
Woody biomass consumption for electricity and biofuels	Low,Medium. High	Demand values in million green tons (Energy Information Administration 2010b)
Urban wood waste	Low,Medium. High	per capita availability (Carter and others 2007)
Harvest residues	Low,Medium. High	SRTS model run based on Johnson and others (2009) data
Forest industry demand	Low,Medium. High	Auxiliary SRTS run for constant prices
Demand elasticity	Low,Medium. High	-0.5 for all products (Abt and others 2010)
Supply elasticity	Low,Medium. High	Different annual values for products based on RPA storylines (Pers. comm. With David Wear March 8, 2010)
Pine productivity	Pine productivity strategy	Pine productivity increases by 100 percent by 2050
All productivity values	All productivity strategy	Pine productivity increases by 100 percent and other forest type increases by 50 percent by 2050
Low productivity values	Low productivity strategy	Pine productivity increases by 50 percent and other forest type increases by 25 percent by 2050
Short rotation woody crops	Short rotation woody crops	Short rotation woody crops take care of 10 percent of total woody biomass for energy demand by 2050
Forest management type acreage	All scenarios and strategies	Forest land change as compared to agriculture and pasture land, in turn impacting acreage of pine plantations, natural pines, oak-pines, upland hardwoods, and lowland hardwoods (Abt and Abt 2010, Hardie and others 2001)
Timber rent	All scenarios and strategies	Weighted average of pulp and sawtimber prices. Model allocates weights, with pulpwood gaining more weight in total rent calculations
Degradation of sawtimber for pulp use	All scenarios and strategies	Percentage allocation of sawtimber that can be used as pulp (Abt and others 2010)
Pulp diameter range	All scenarios and strategies	<9 inch softwood <13 inch hardwood

Saw diameter range	All scenarios and strategies	>9 inch softwood >13 inch hardwood
Forest products	All scenarios and strategies	Sawtimber softwoods, other softwoods, sawtimber hardwoods, and other hardwoods

Table 10-4—Financial incentives for renewable energy at Federal and State levels: Number in the parentheses mean whether incentives are State governments(S) or red, green is utility companies (U), purple is local governments(L), yellow is nonprofit organizations(N).(source: Database of State Incentives for Renewables and Efficiency, available at http://www.dsireusa.org/summarytables/finre.cfm)

State(s)		Corporate tax	Sales tax	Property tax	Rebates	Grants	Loans	Industry support	Performance based incentive
All States (Federal incentives)	3	4				3	5	1	1
Alabama	1(1S)				3(3U)	1(1S)	3(1S,2U)		1(1U)
Arkansas					2(1S,1U)		1(1U)	1(1S)	
Florida		2(2S)	2(2S)		12(1S,10U,1L)		6(1S,5U)	1(1L)	2(2U)
Georgia	1(1S)	1(1S)	1(1S)		10(1S,9U)		1(1S)		2(2U)
Kentucky	1(1S)	2(2S)	1(1S)		11(1S,10U)	1(S)	4(1S,1U,1L,1N)		1(1S)
Louisiana	1(1S)	1(1S)		1(S)			2(2S)		
Mississippi					5(1S,4U)		4(1S,3U)		1(S)
North Carolina	1(1S)	1(1S)	1(1S)	2(2S)	6(6U)	1(1S)	4(3S,1U)		4(3S,1N)
Oklahoma		1(1S)			3(3U)		6(4S,2(U)	1(S)	
South Carolina	1(1S)	2(2S)	1(1S)		6(6U)		6(1S,5U)		4(1S,2U,1N)
Tennessee				1(S)	2(1S,1U)	2(2S)	3(2S,1U)	1(S)	1(S)
Texas		1(1S)		1(1S)	27(25U,2L)	2(2S)	2(2S)	1(1S)	2(2U)
Virginia				1(1S)	1(1S)		1(1S)	1(1S)	1(1U)
Total	9	15	6	6	88	10	48	7	20

Figures

Figure 10-1—Methodology diagram for modified Subregional Timber Supply model used to project levels and effects of woody biomass consumed for energy for the South.

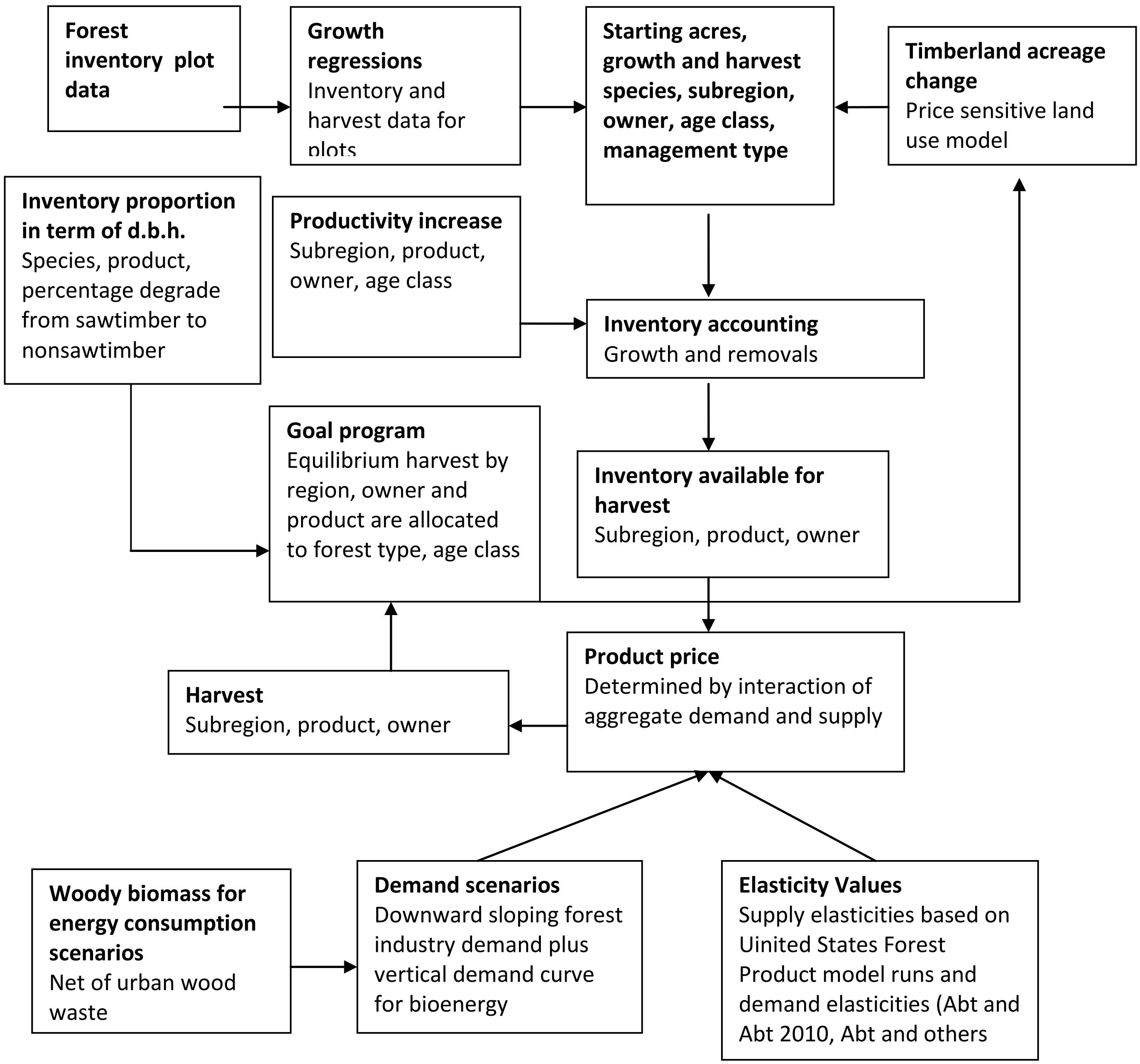


Figure 10-2—Woody biomass demand for energy in the South under low-, medium-, and high-consumption scenarios; with demand from traditional forest industry and availability from urban wood waste, 2010 to 2050.

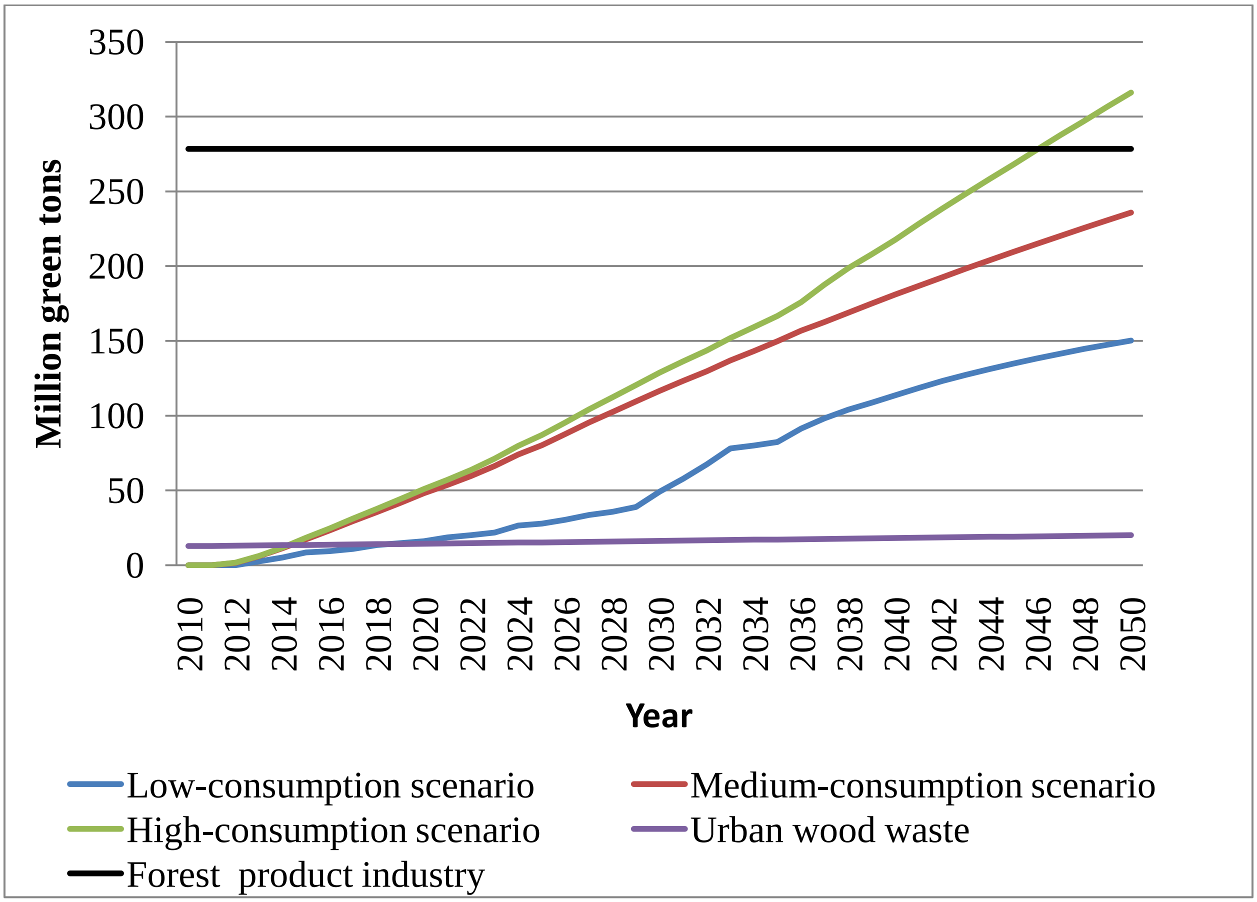
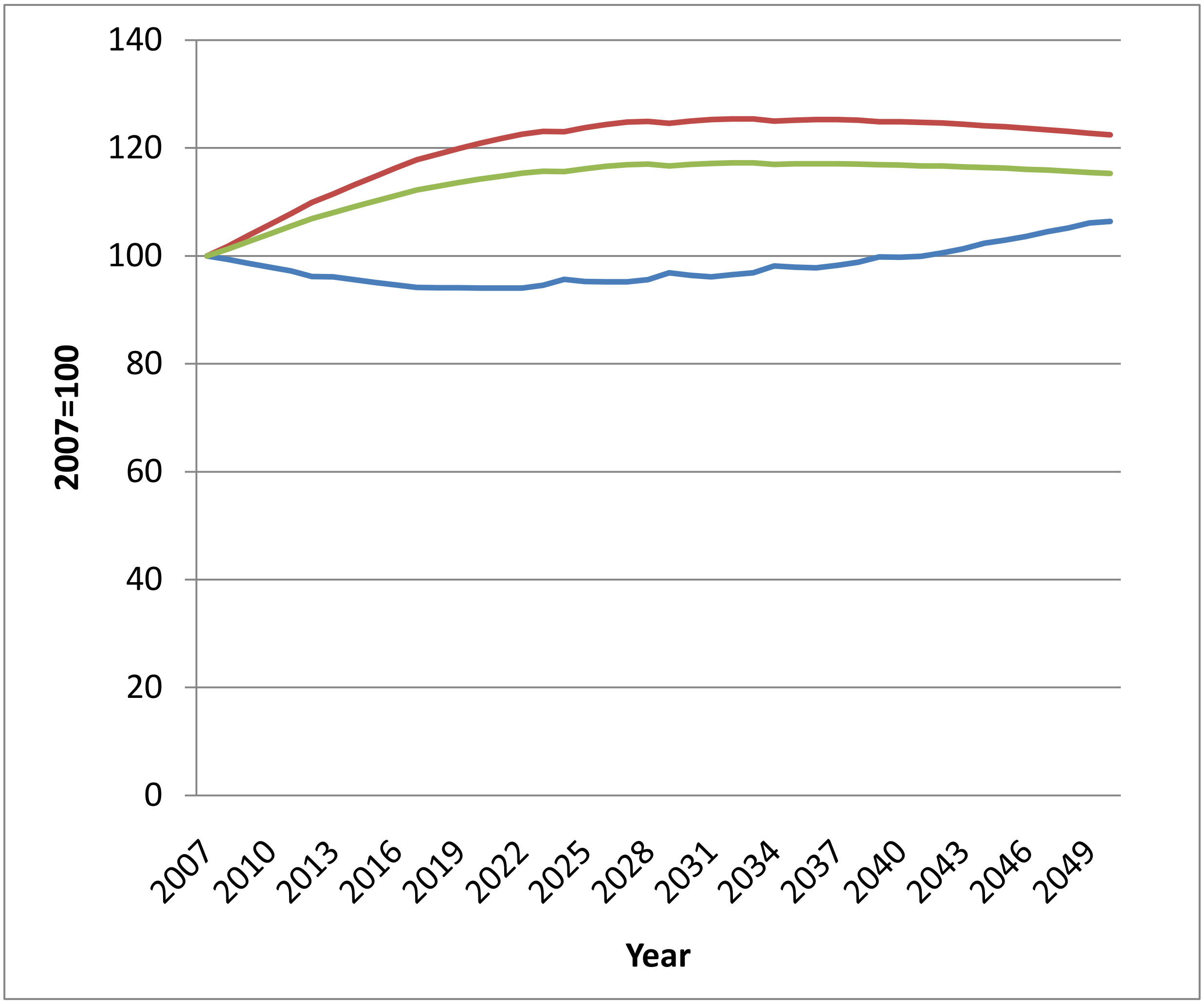
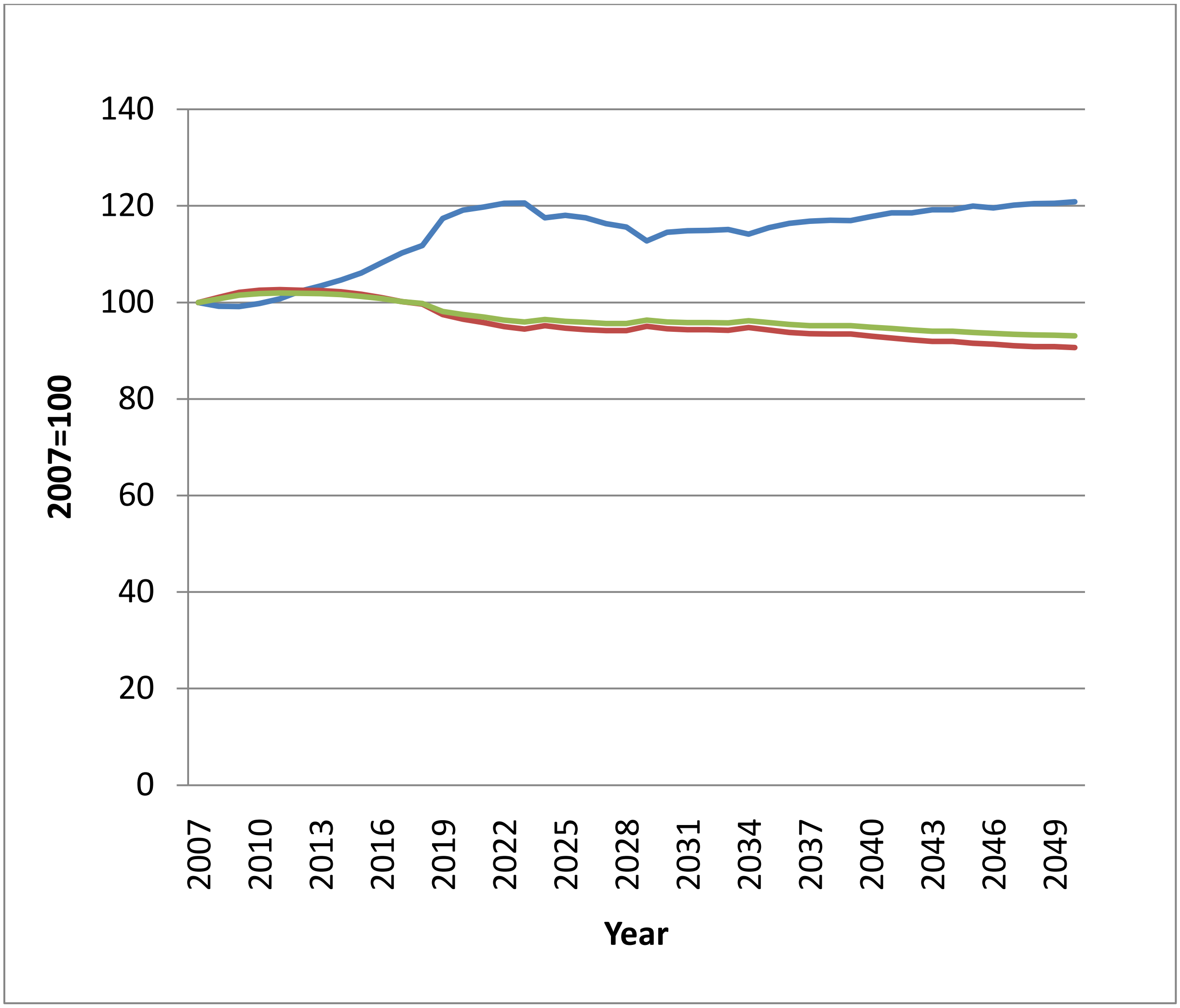


Figure 10-3—Market responses in price, inventory, and removals for southern (A) softwood sawtimber, (B) other softwoods, (C) hardwood sawtimber, and (D) other hardwoods in a constant forest industry consumption scenario (no biomass diverted to energy).

(A)

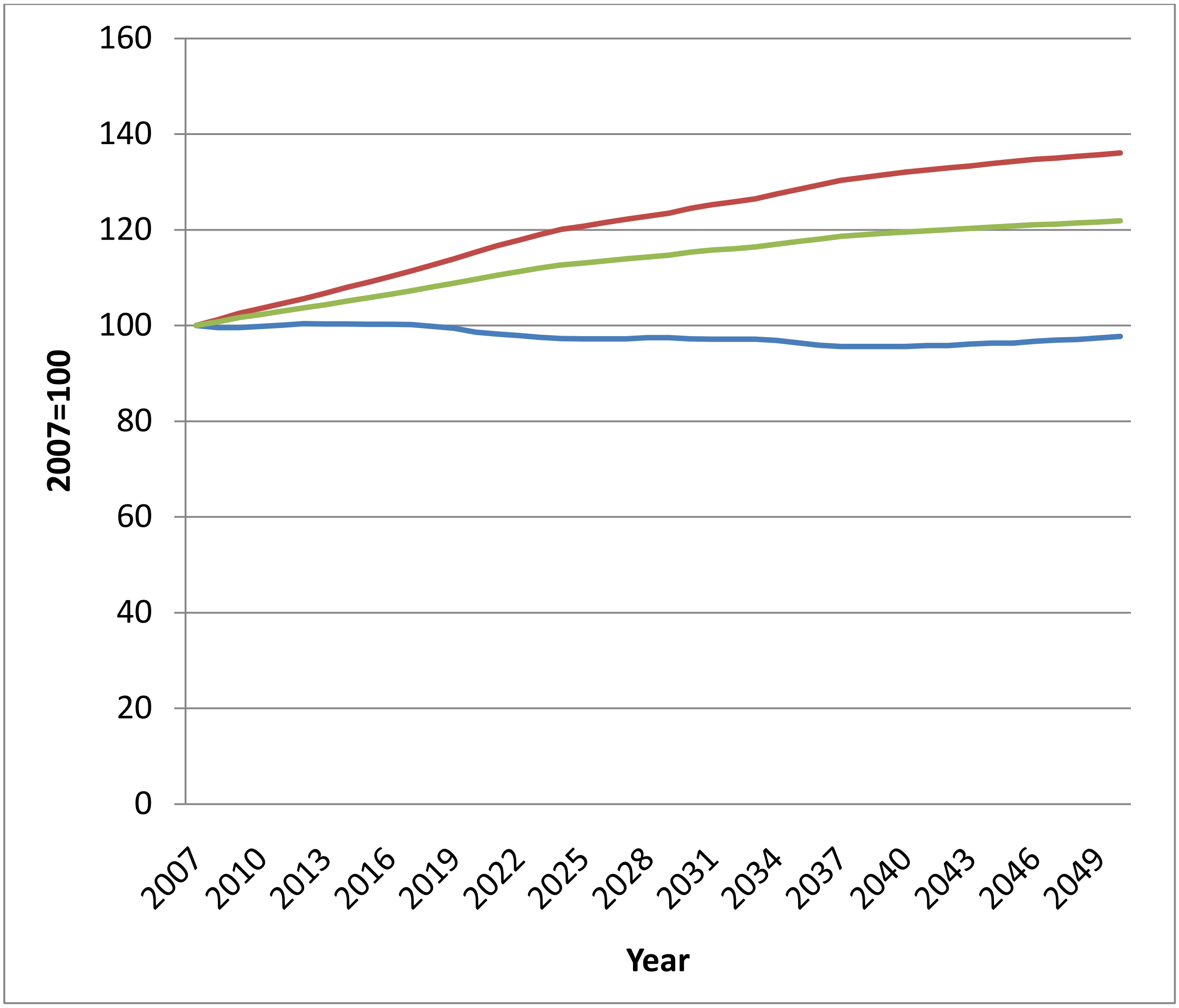


(B)



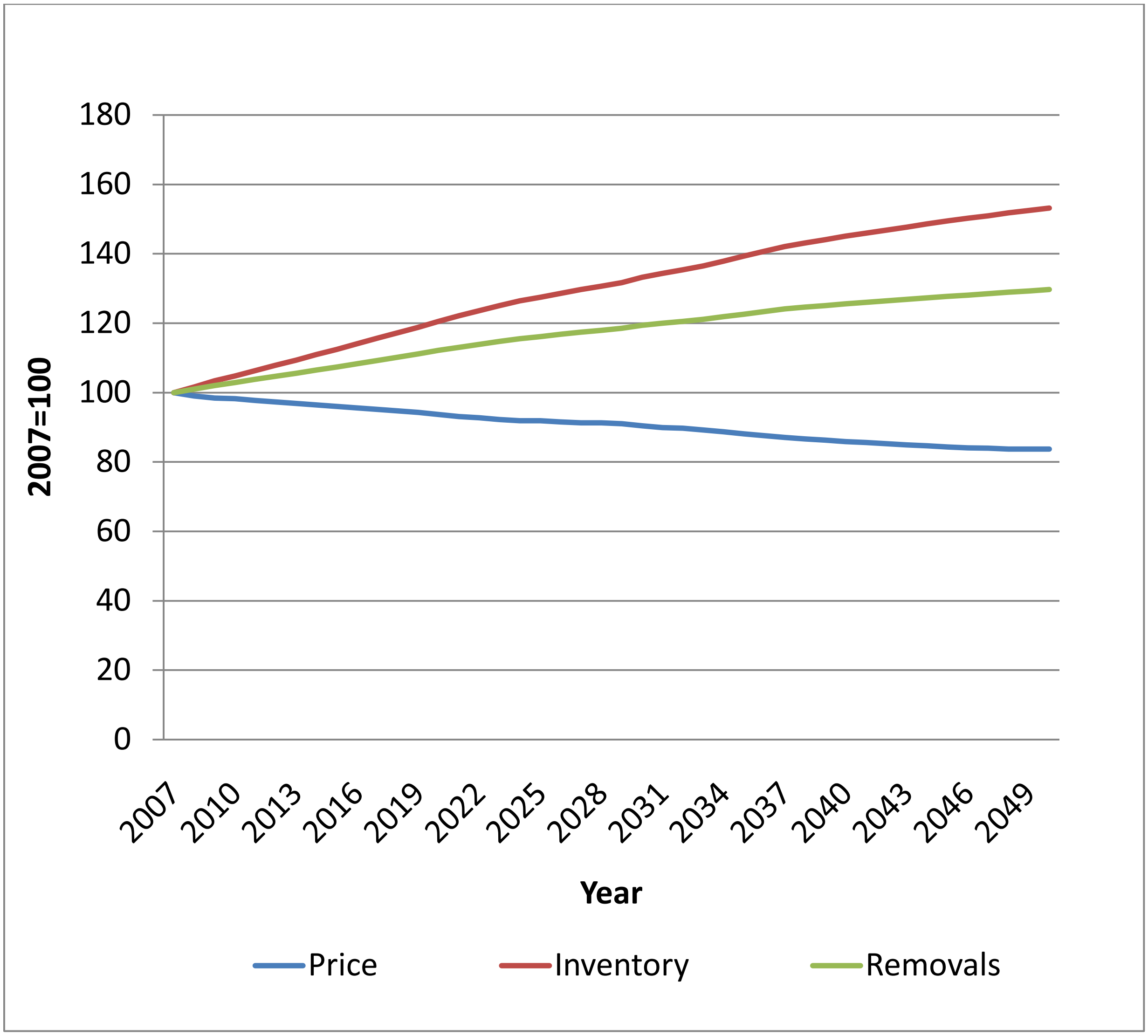
140
120
100
80
60
40
20
0
2007=100
2007
2010
2013
2016
2019
2022
2025
2028
2031
2034
2037
2040
2043
2046
2049
Year

(C)



160
140
120
100
80
60
40
20
0
2007=100
2007
2010
2013
2016
2019
2022
2025
2028
2031
2034
2037
2040
2043
2046
2049
Year

(D)



180
160
140
120
100
80
60
40
20
0
2007=100
2007
2010
2013
2016
2019
2022
2025
2028
2031
2034
2037
2040
2043
2046
2049
Year
Price
Inventory
Removals

Figure 10-4—Private forest acreage change in the South under a constant forest industry consumption scenario (no biomass diverted to energy).

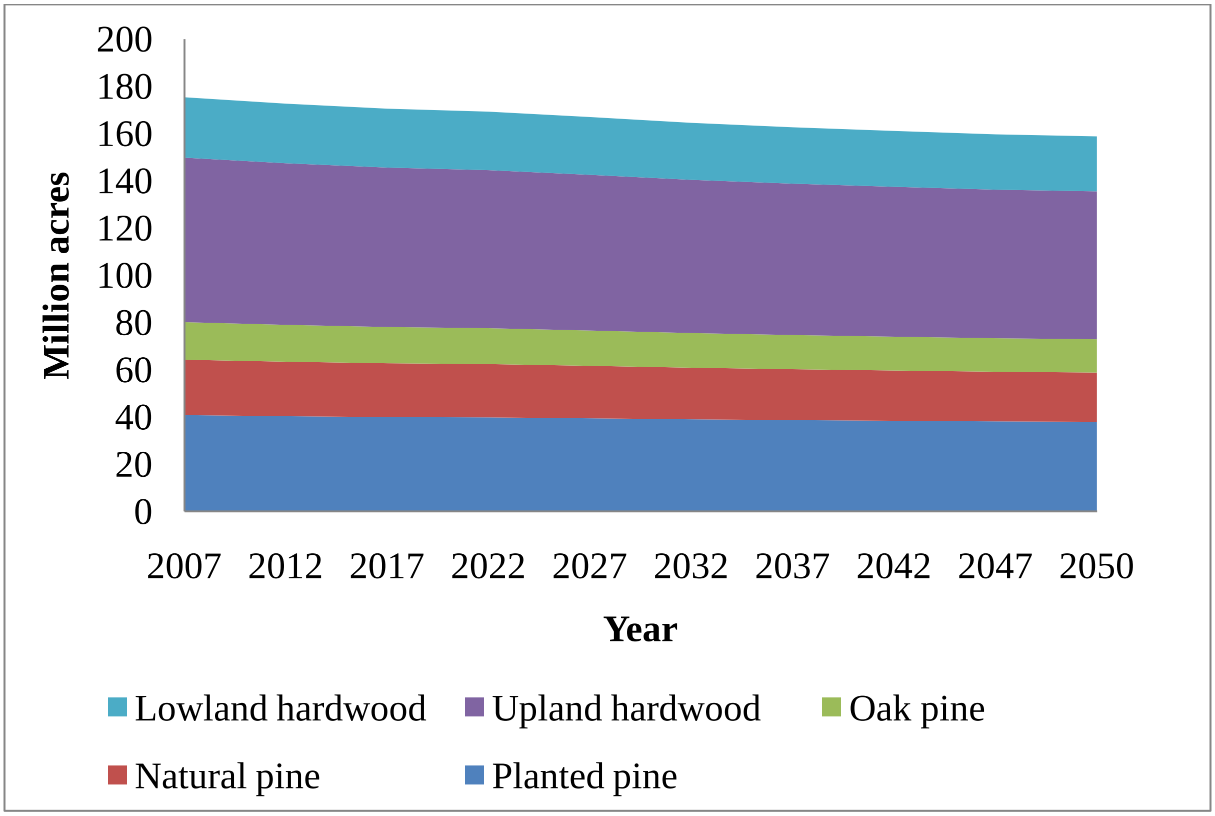
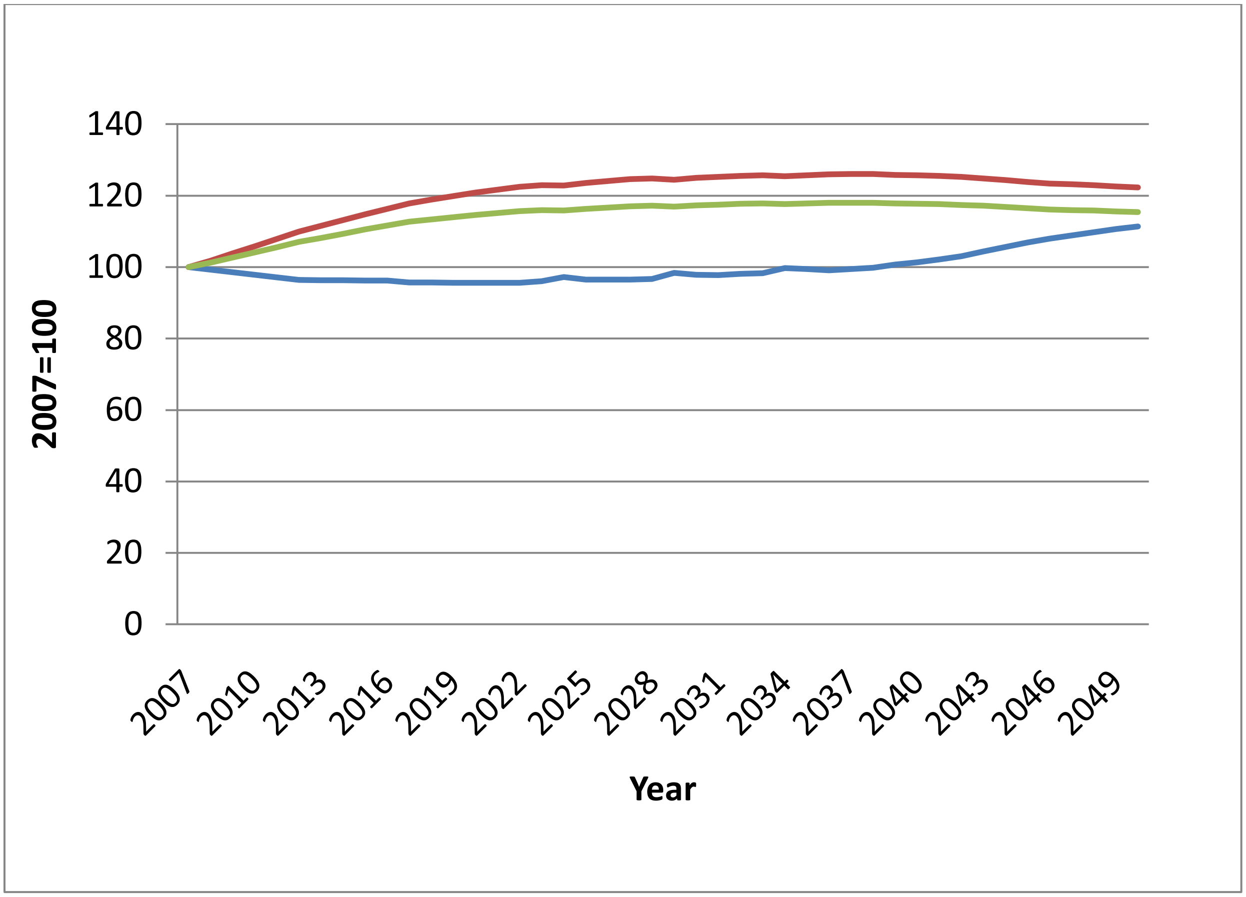
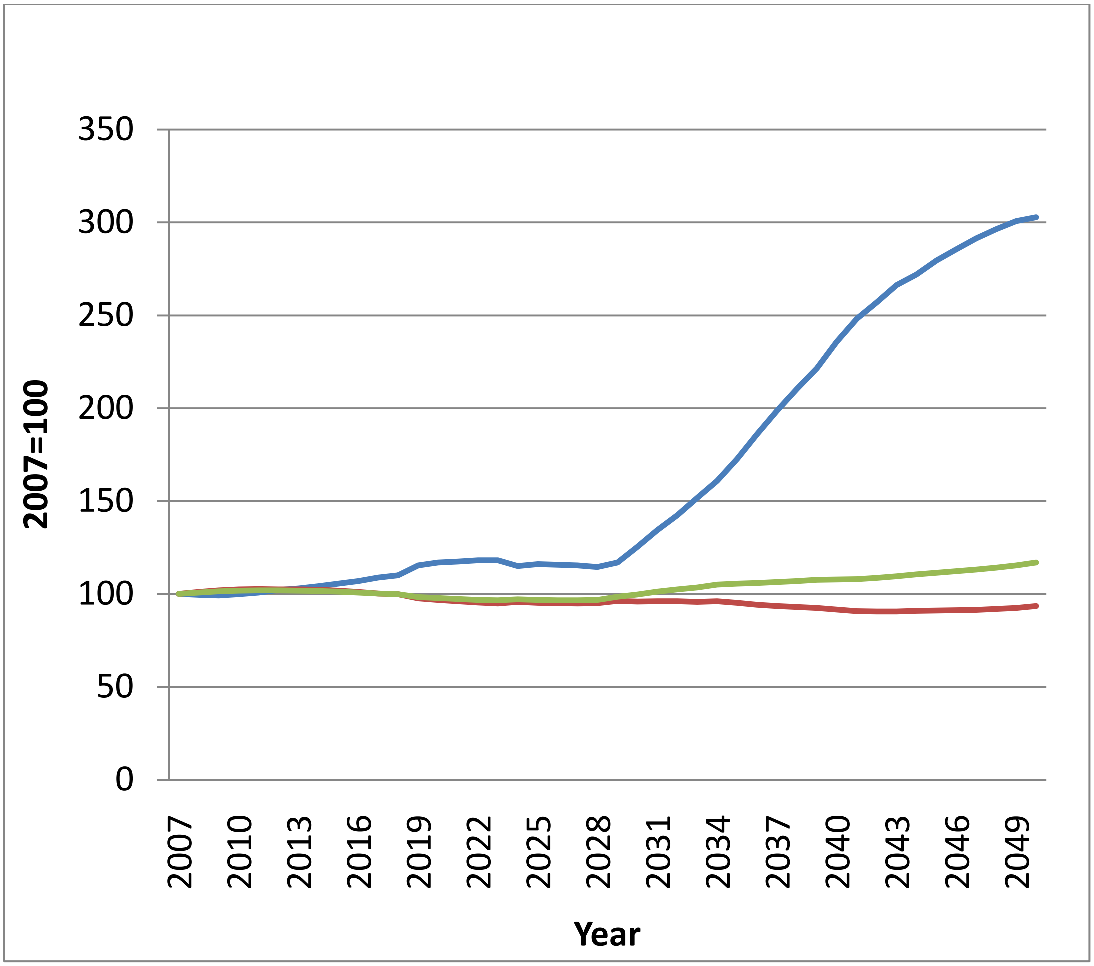


Figure 10-5—Market responses in price, inventory, and removals for southern (A) softwood sawtimber, (B) other softwoods, (C) hardwood sawtimber, and (D) other hardwoods, assuming low consumption of woody biomass for energy.

(A)

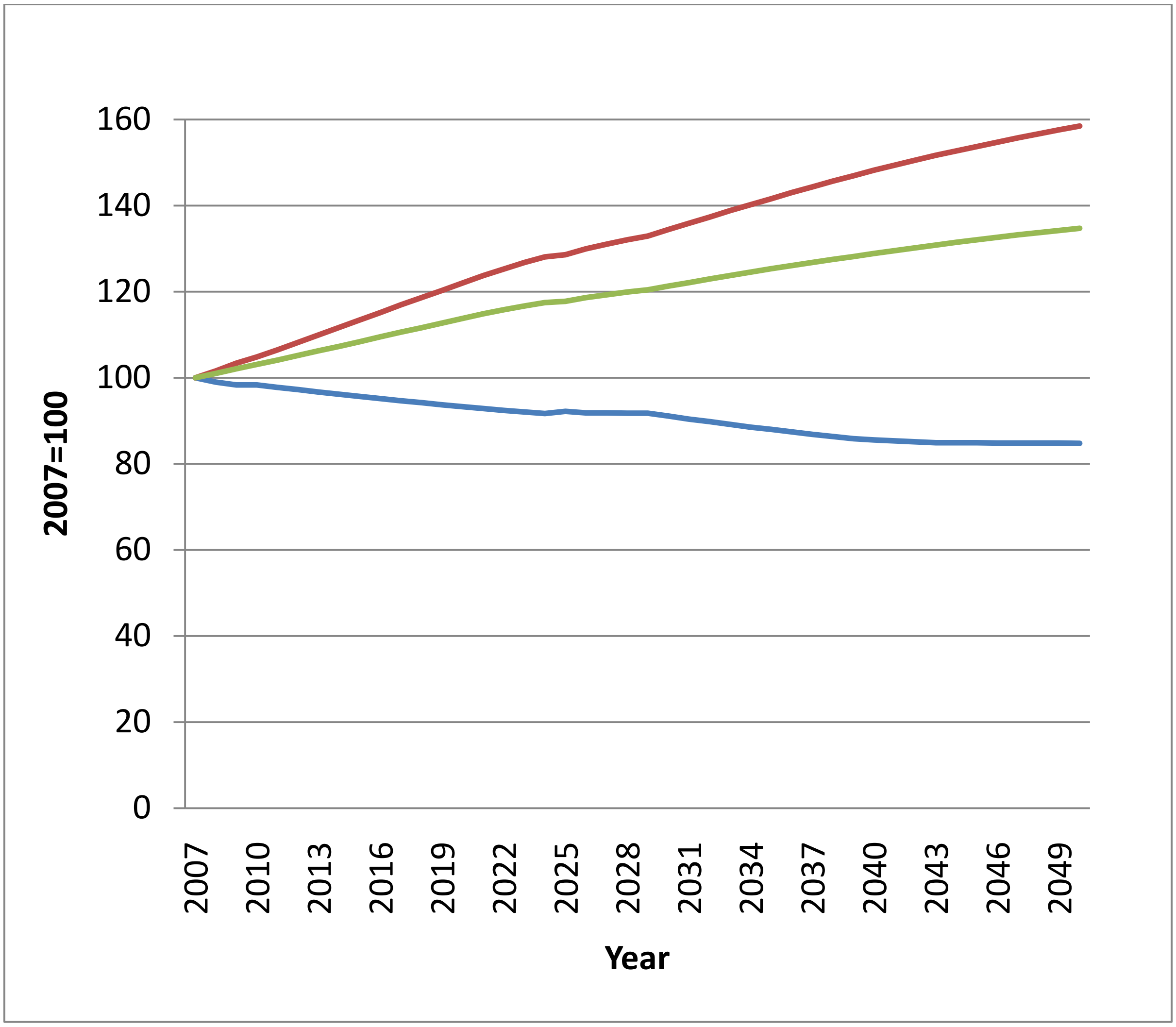


(B)



350
300
250
200
150
100
50
0
2007=100
2007
2010
2013
2016
2019
2022
2025
2028
2031
2034
2037
2040
2043
2046
2049
Year

(C)



160
140
120
100
80
60
40
20
0
2007=100
2007
2010
2013
2016
2019
2022
2025
2028
2031
2034
2037
2040
2043
2046
2049
Year

(D)

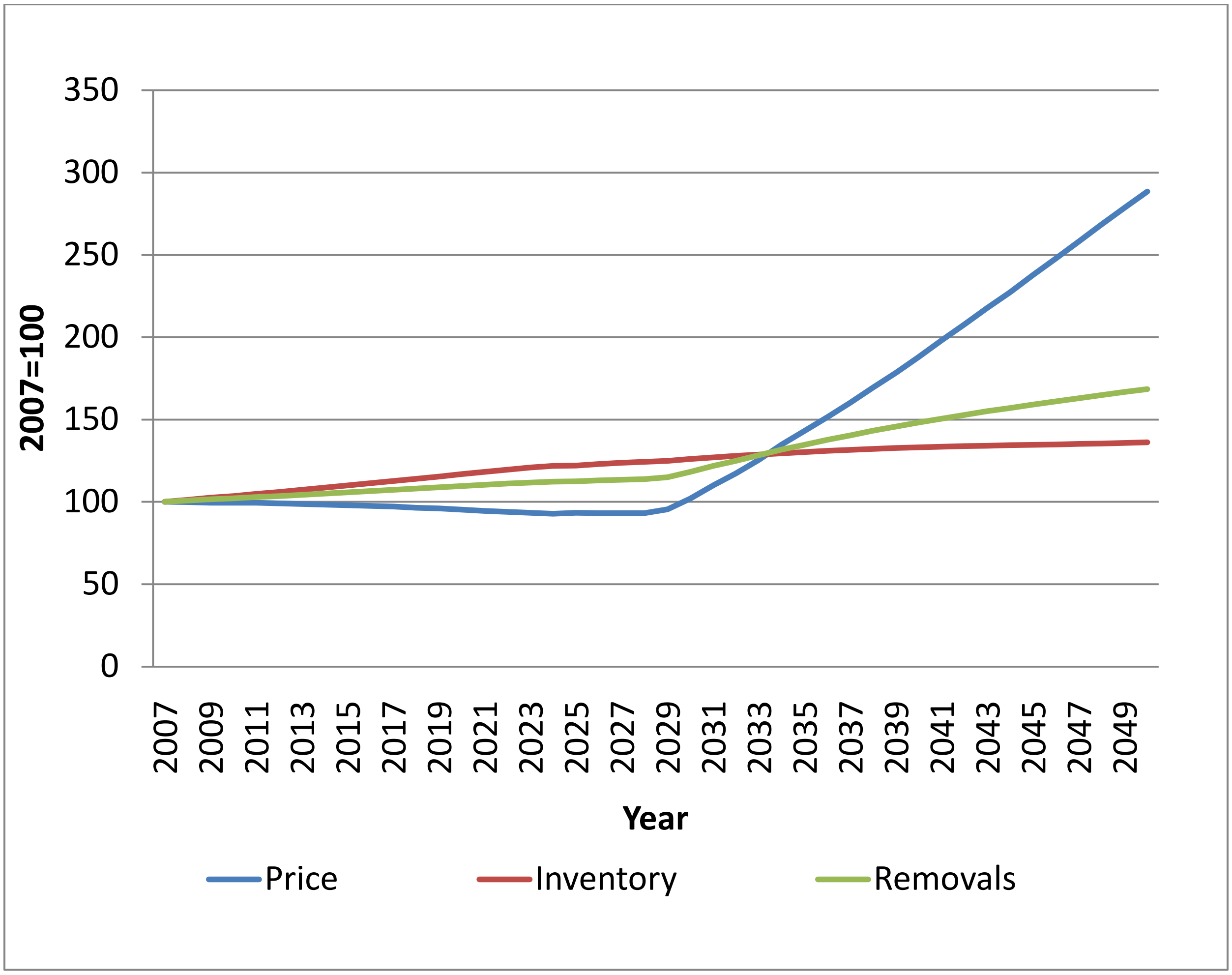

350
300
250
200
150
100
50
0
2007=100
2007
2009
2011
2013
2015
2017
2019
2021
2023
2025
2027
2029
2031
2033
2035
2037
2039
2041
2043
2045
2047
2049
Year
Price
Inventory
Removals

Figure 10-7—Private forest acreage change in the South, assuming low consumption of woody biomass for energy.

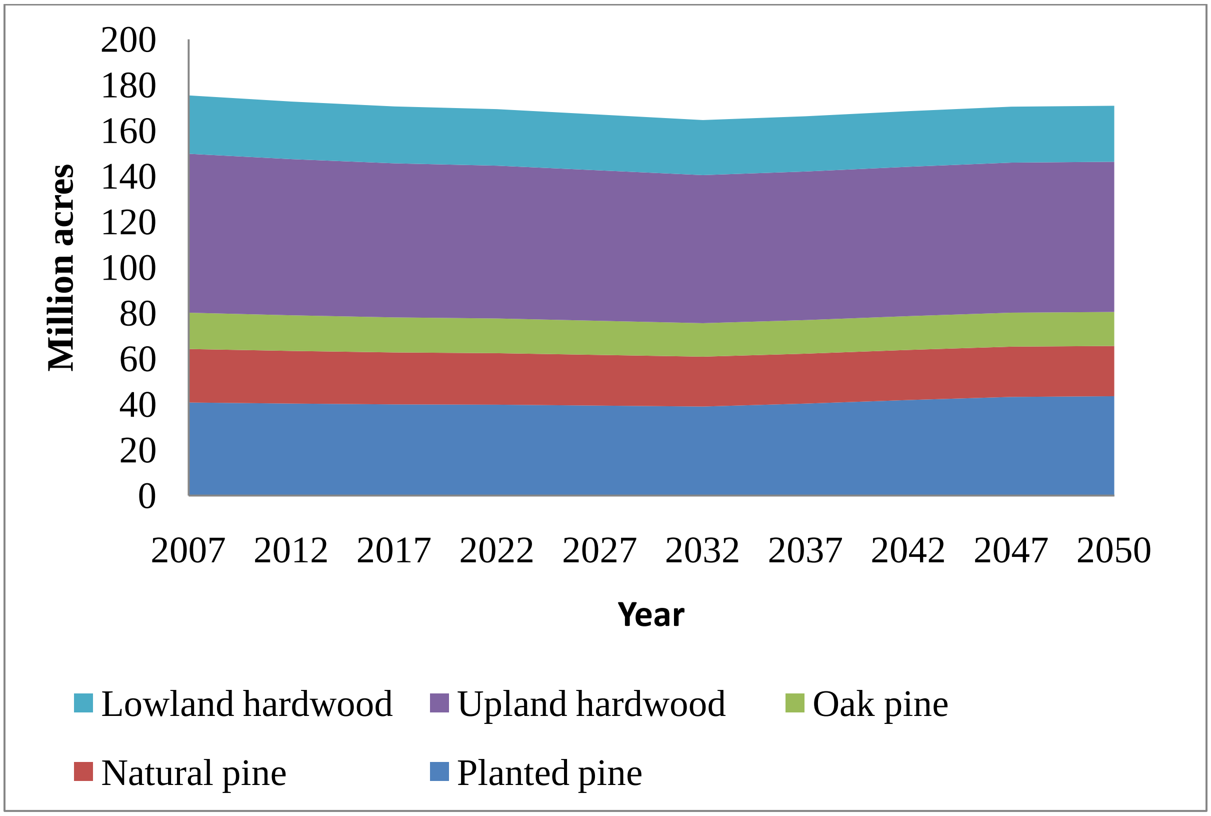


Figure 10-6—Feedstock composition in the South, assuming low consumption of woody biomass for energy.

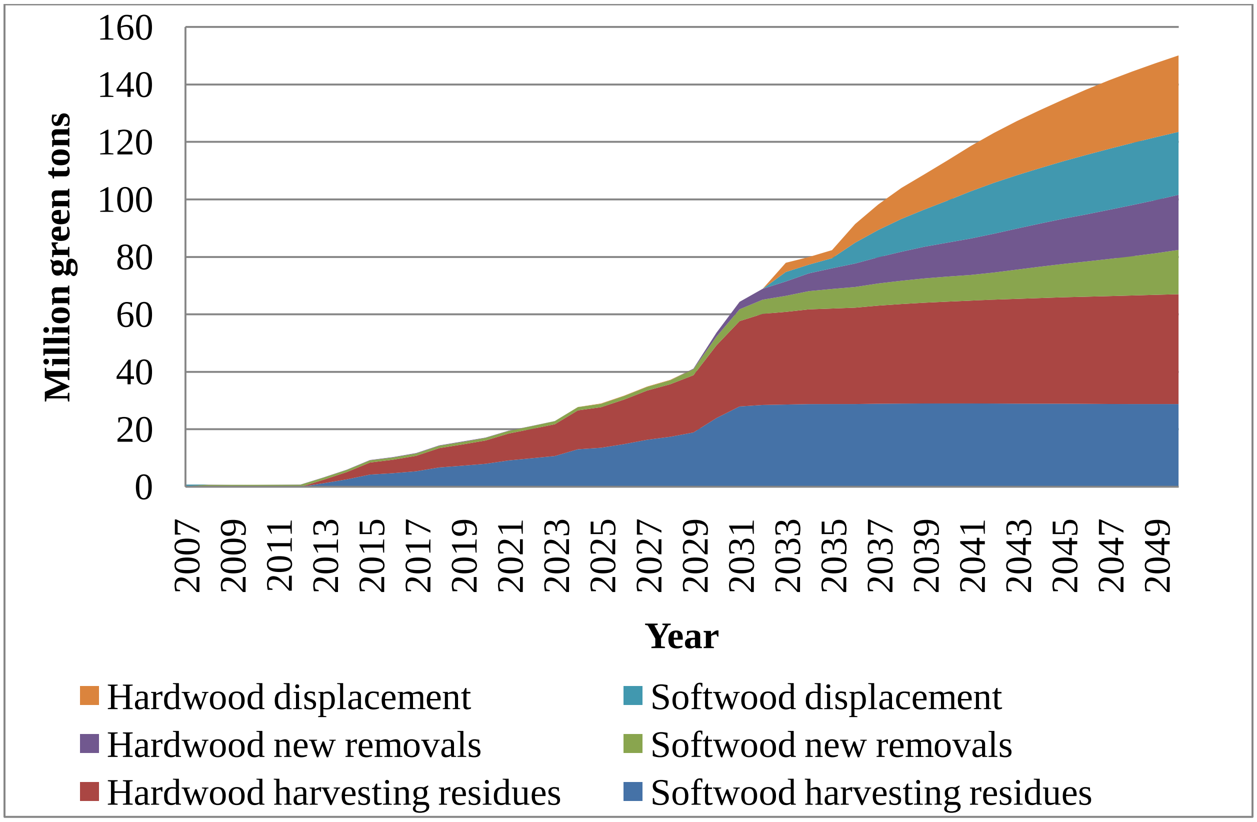
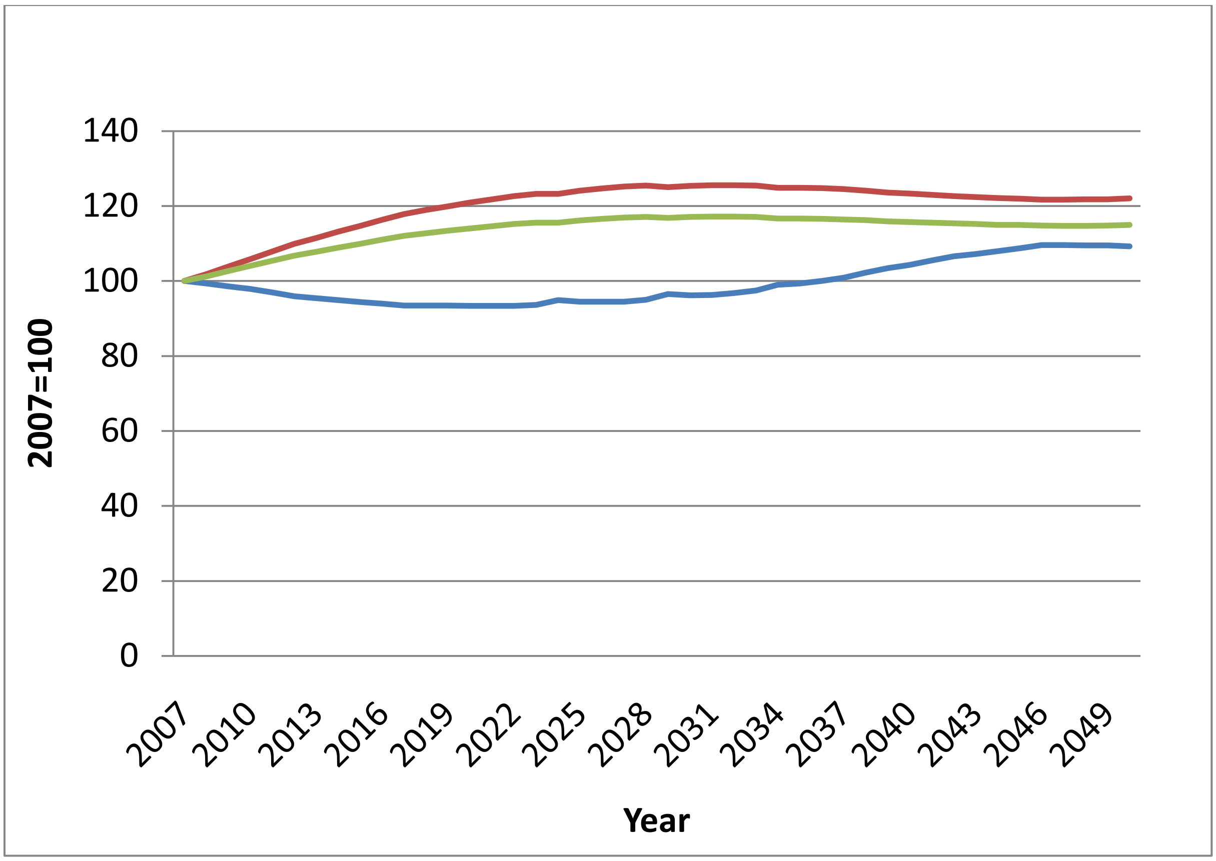
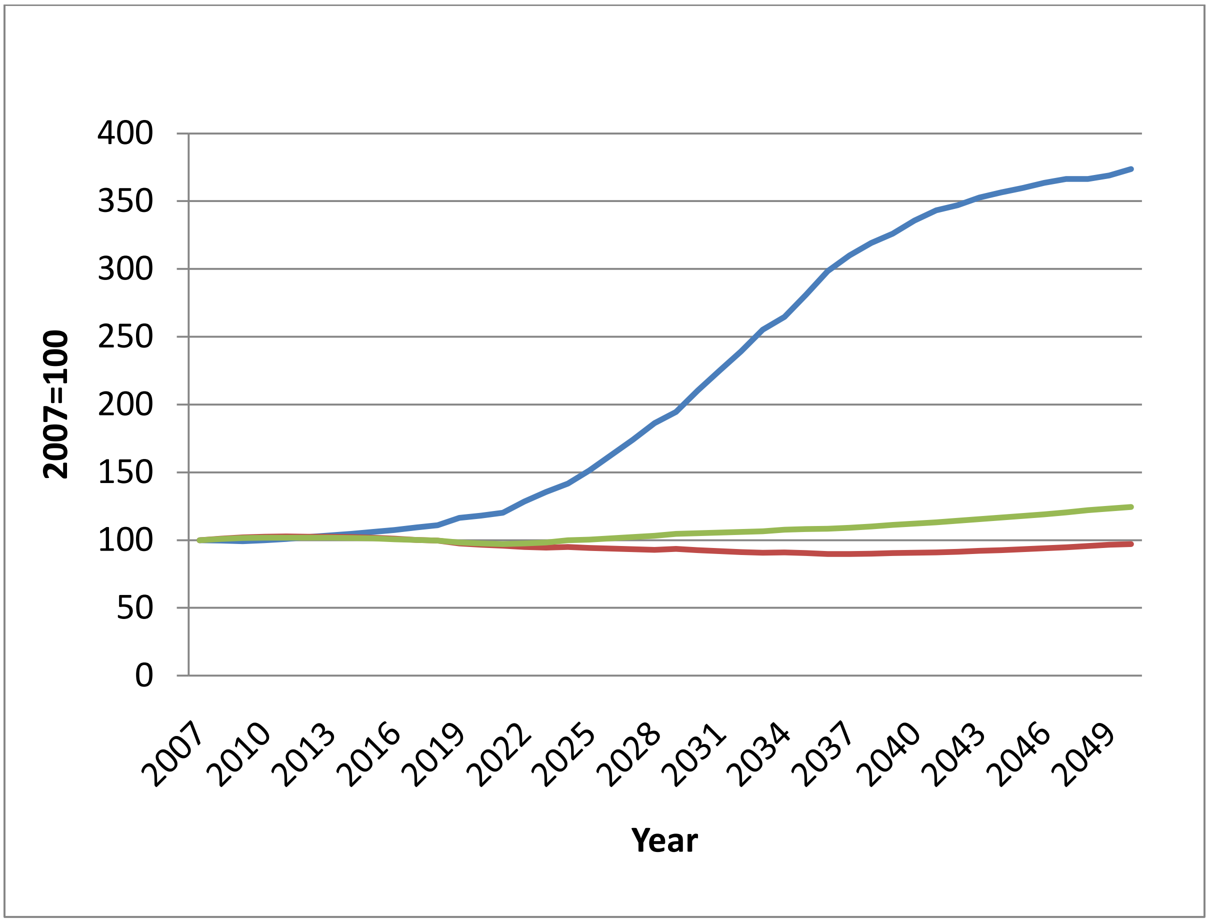


Figure 10-8—Market responses in price, inventory, and removals for southern (A) softwood sawtimber, (B) other softwoods, (C) hardwood sawtimber, and (D) other hardwoods, assuming moderate consumption of woody biomass for energy.

(A)

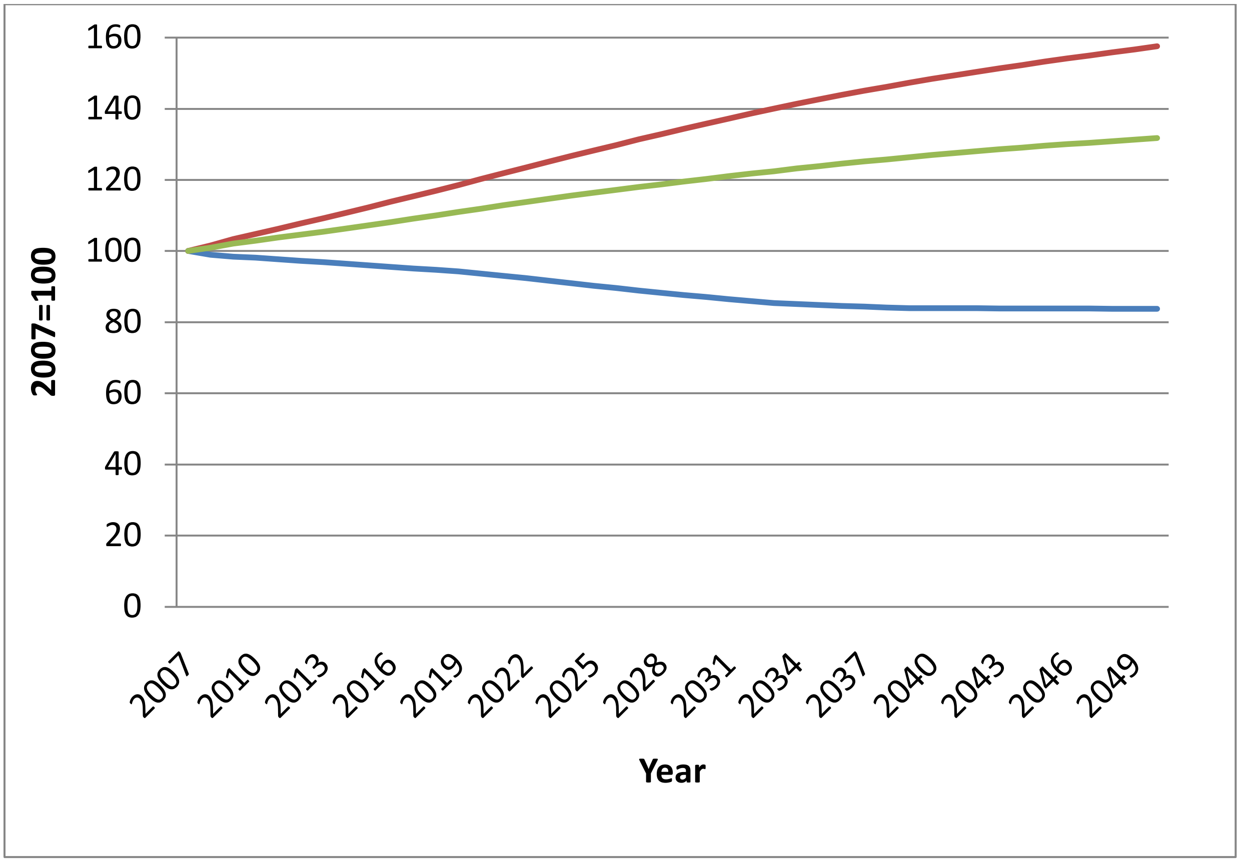


(B)



400
350
300
250
200
150
100
50
0
2007=100
2007
2010
2013
2016
2019
2022
2025
2028
2031
2034
2037
2040
2043
2046
2049
Year

(C)



160
140
120
100
80
60
40
20
0
2007=100
2007
2010
2013
2016
2019
2022
2025
2028
2031
2034
2037
2040
2043
2046
2049
Year

(D)

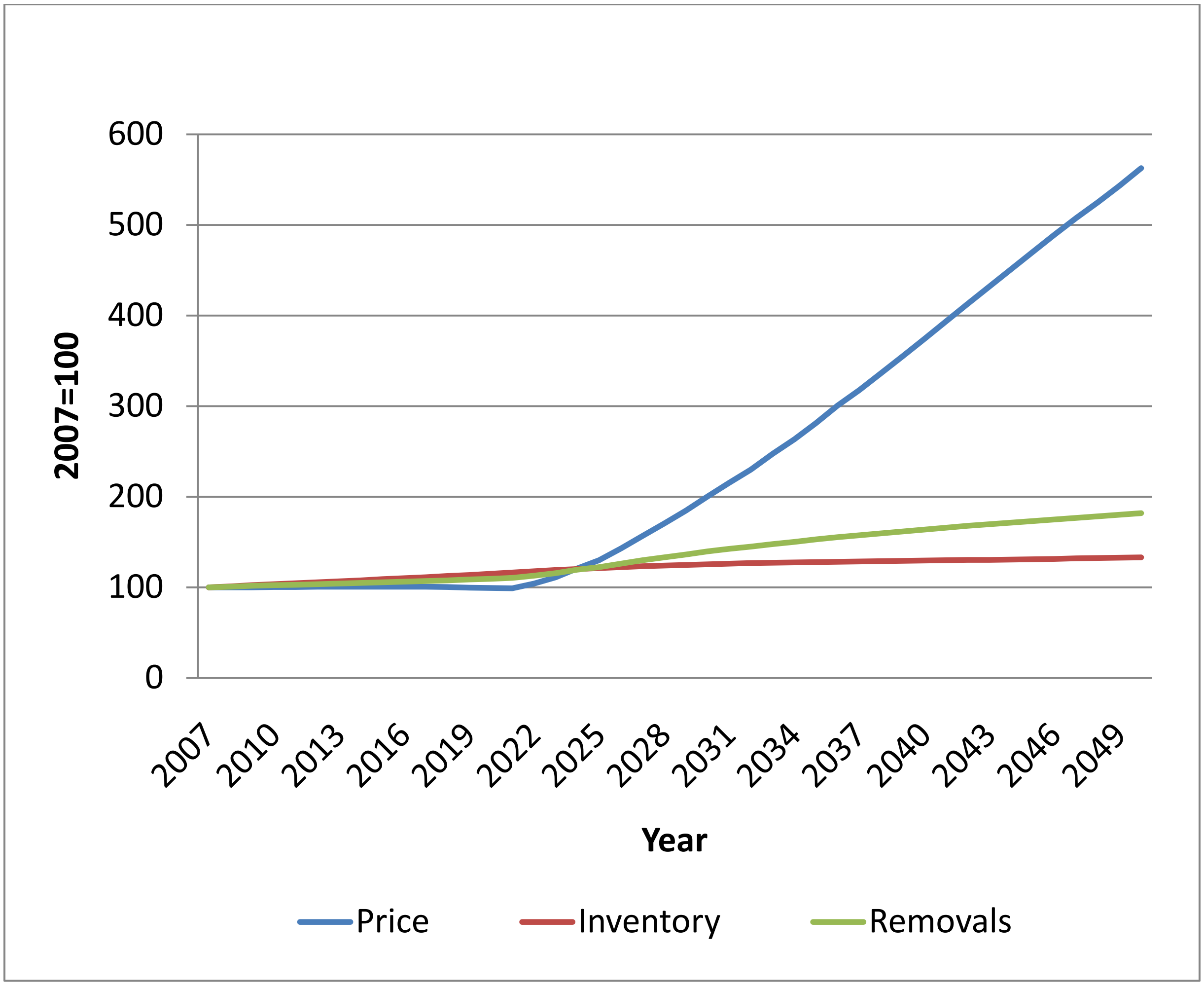

600
500
400
300
200
100
0
2007=100
2007
2010
2013
2016
2019
2022
2025
2028
2031
2034
2037
2040
2043
2046
2049
Year
Price
Inventory
Removals

Figure 10-9—Feedstock composition in the South, assuming moderate consumption of woody biomass for energy.

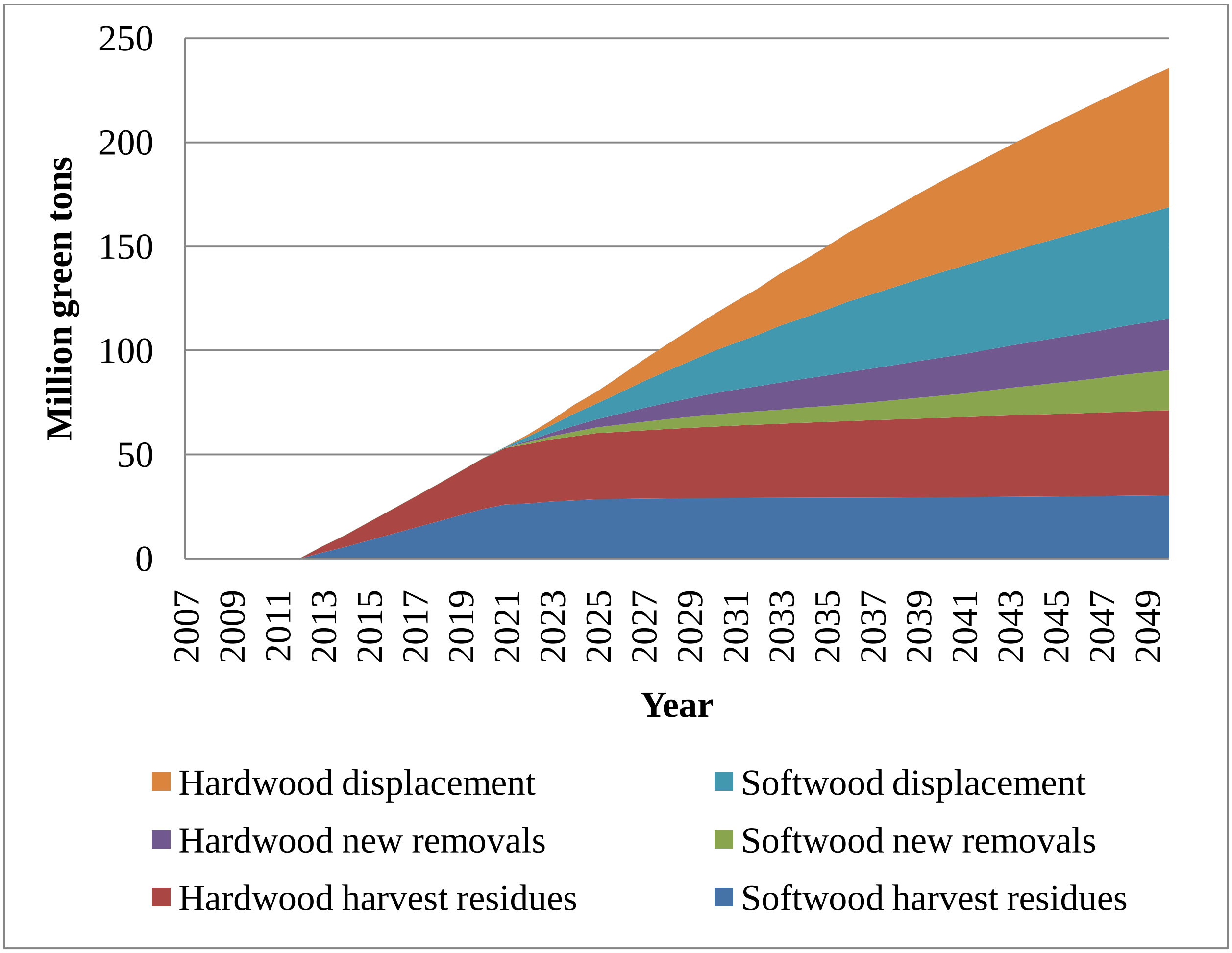


Figure 10-10—Private forest acreage change in the South, assuming moderate consumption of woody biomass for energy.

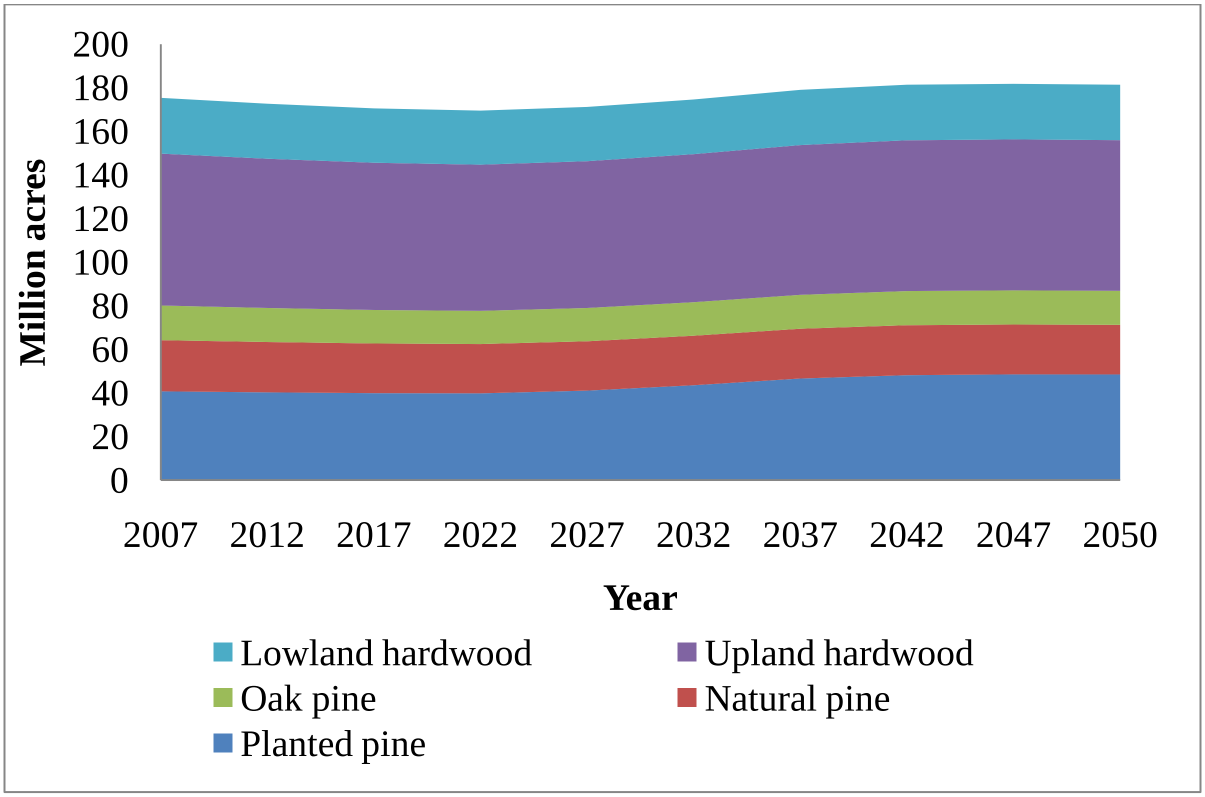
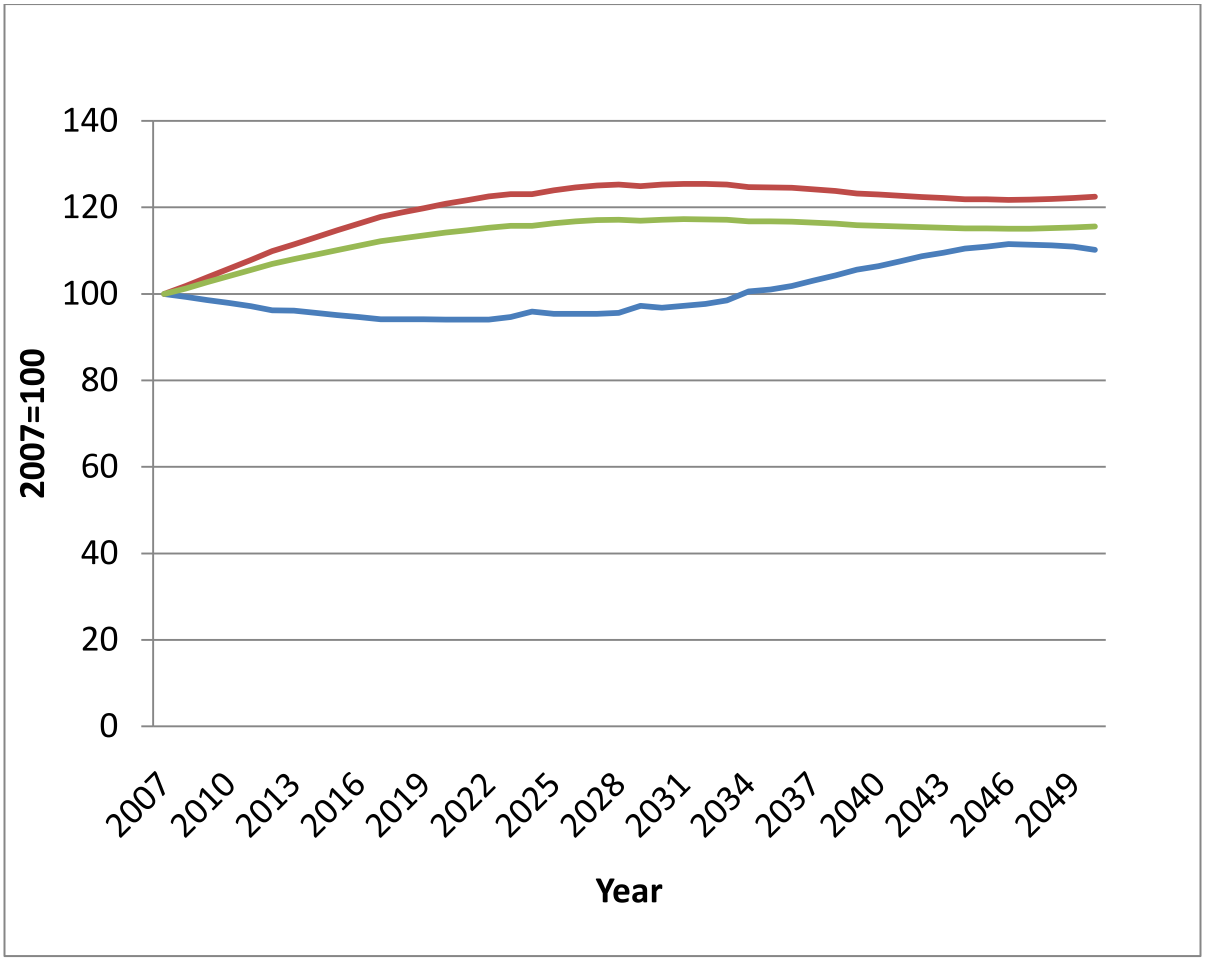
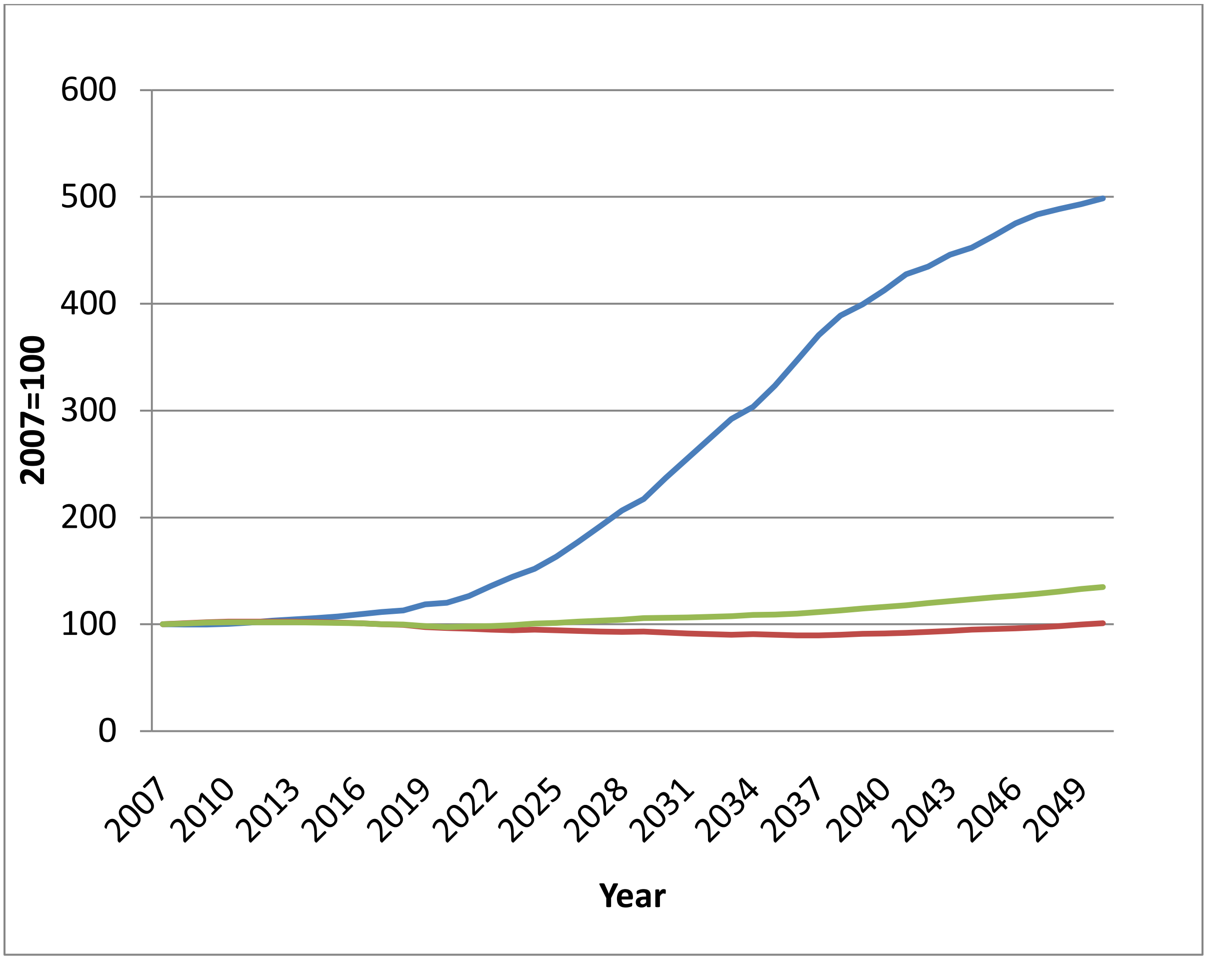


Figure 10-11—Market responses in price, inventory, and removals for southern (A) softwood sawtimber, (B) other softwoods, (C) hardwood sawtimber, and (D) other hardwoods, assuming high consumption of woody biomass consumption for energy.

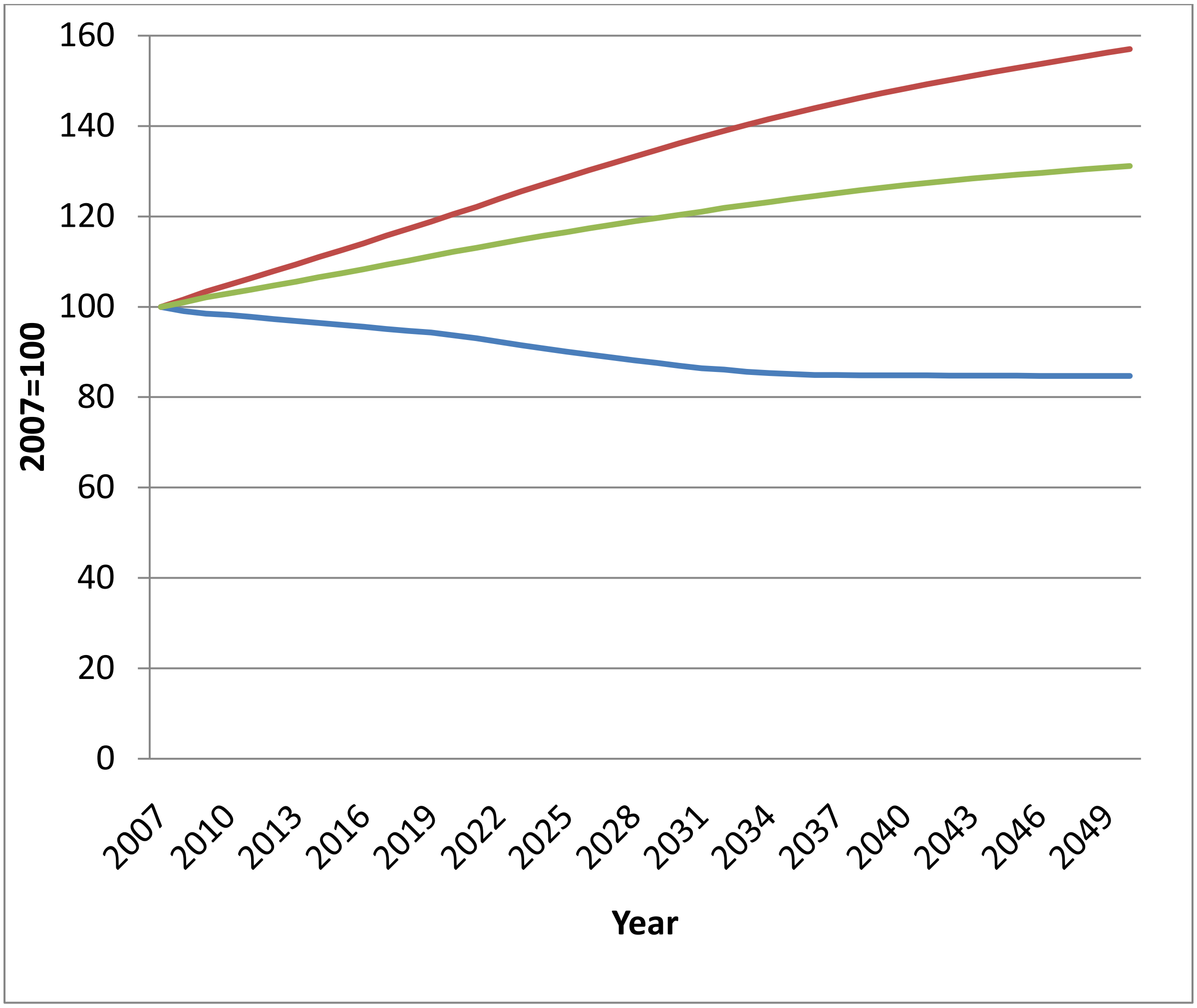
(A)



(B)


600
500
400
300
200
100
0
2007=100
2007
2010
2013
2016
2019
2022
2025
2028
2031
2034
2037
2040
2043
2046
2049
Year

(C)


160
140
120
100
80
60
40
20
0
2007=100
2007
2010
2013
2016
2019
2022
2025
2028
2031
2034
2037
2040
2043
2046
2049
Year

(D)


900
800
700
600
500
400
300
200
100
0
2007=100
2007
2010
2013
2016
2019
2022
2025
2028
2031
2034
2037
2040
2043
2046
2049
Year
Price
Inventory
Removals

Figure 10-12—Feedstock composition in the South, assuming high consumption of woody biomass for energy.

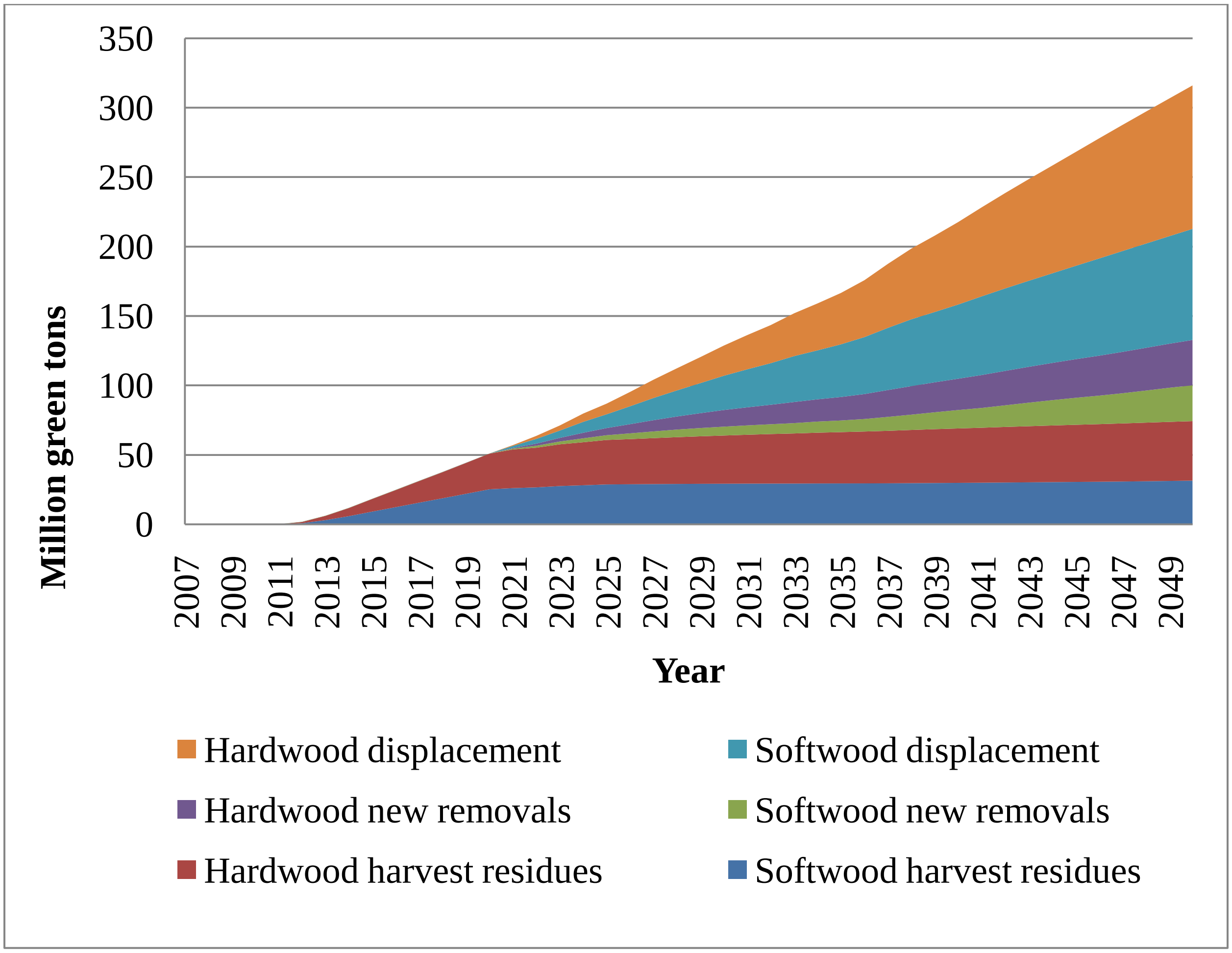


Figure 10-13—Private forest acreage change in the South, assuming high consumption of woody biomass for energy.

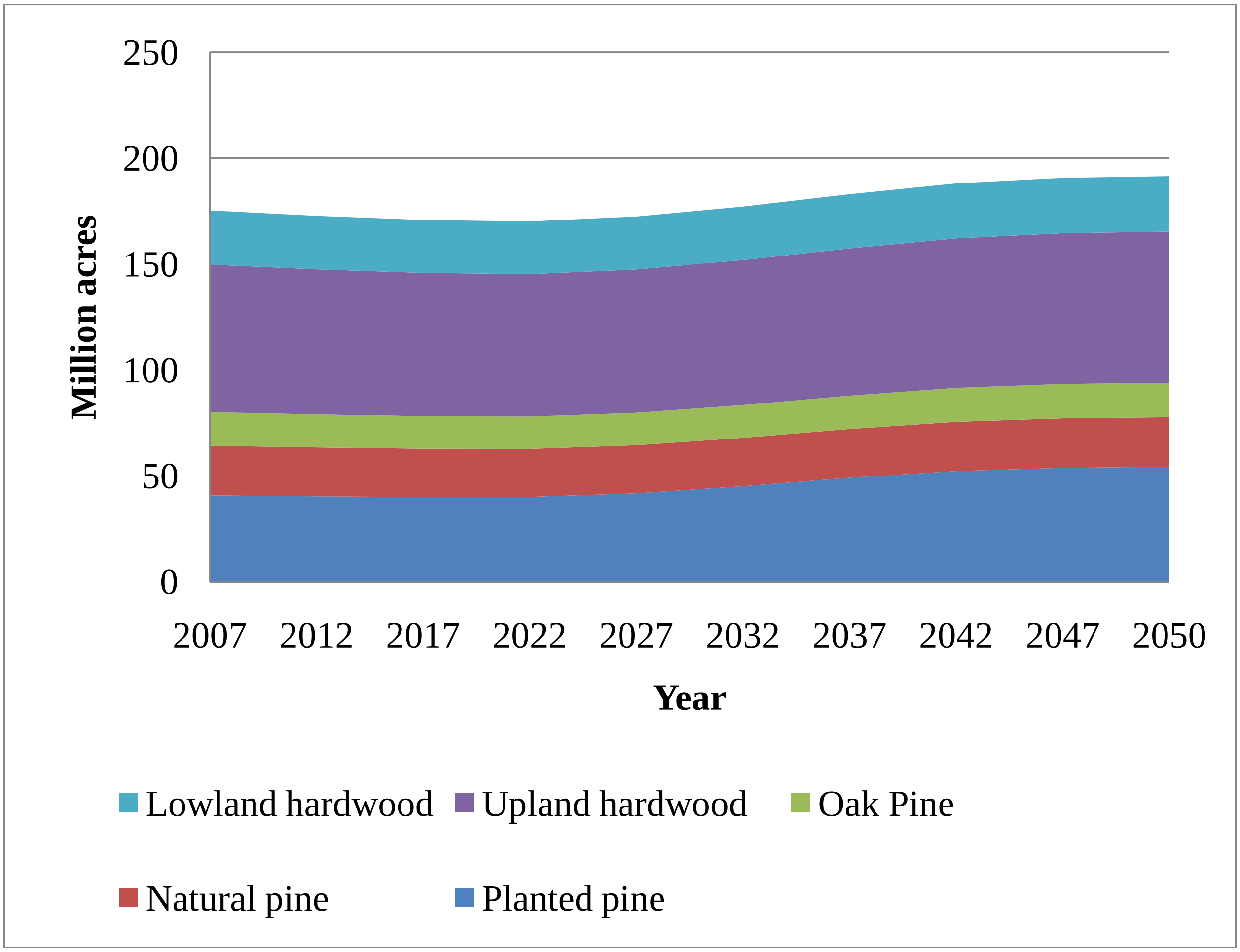
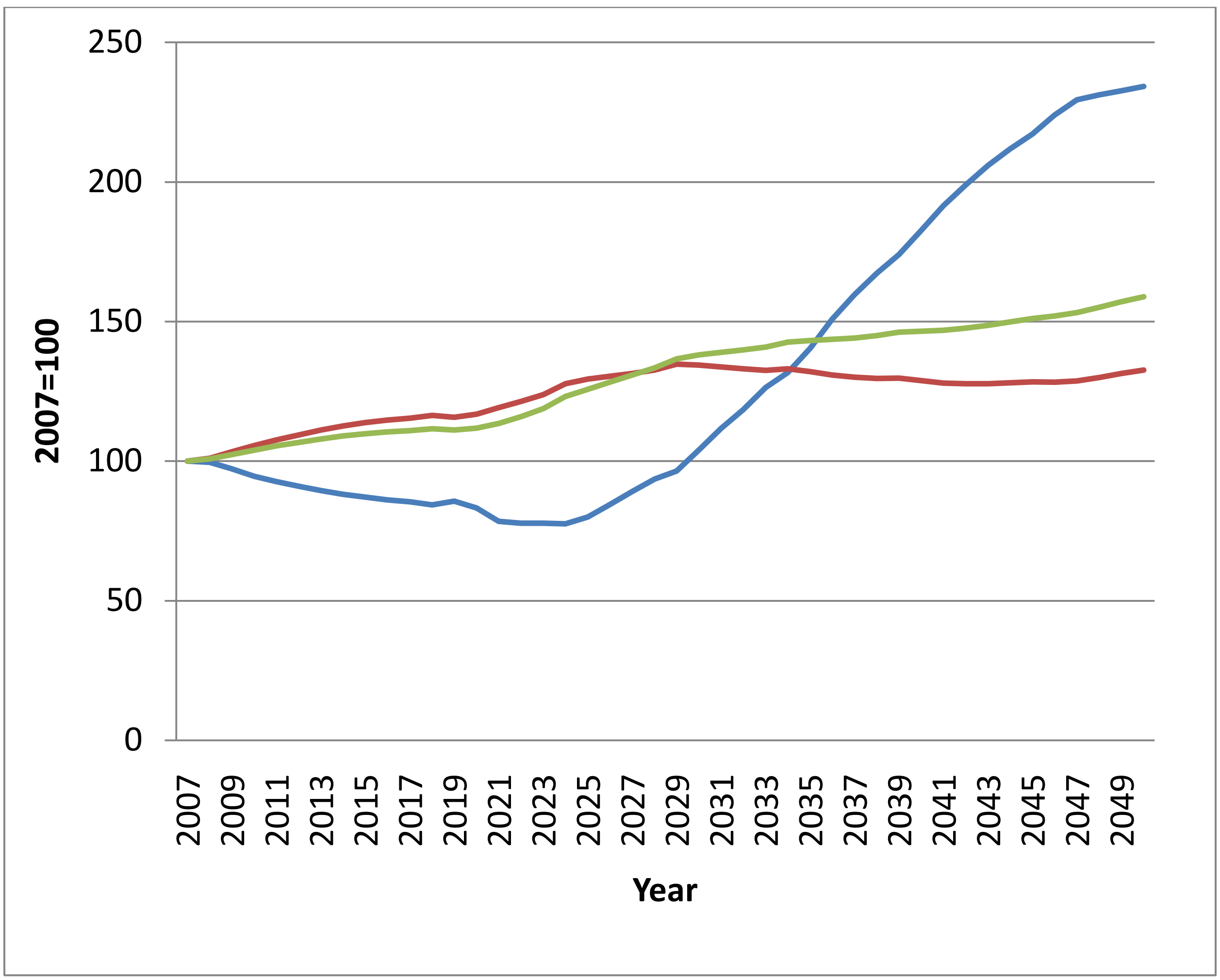
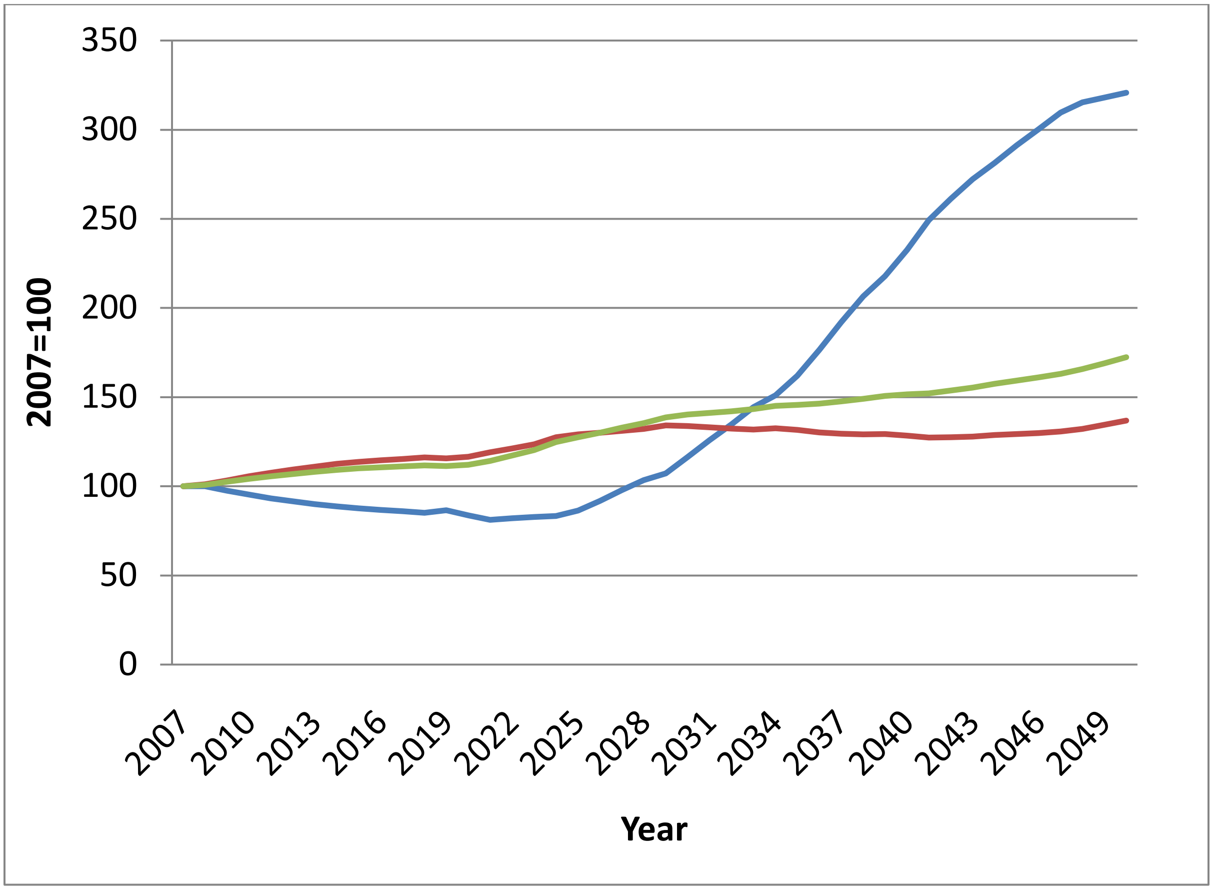


Figure 10-14—Under a productivity strategy that is limited to pine plantations, market responses in price, inventory, and removals for southern (A) nonsawtimber softwoods and (B) nonsawtimber hardwoods—both assuming moderate consumption of woody biomass for energy; and for southern (C) nonsawtimber softwoods and (D) nonsawtimber hardwoods—both assuming high consumption of woody biomass for energy.

(A)

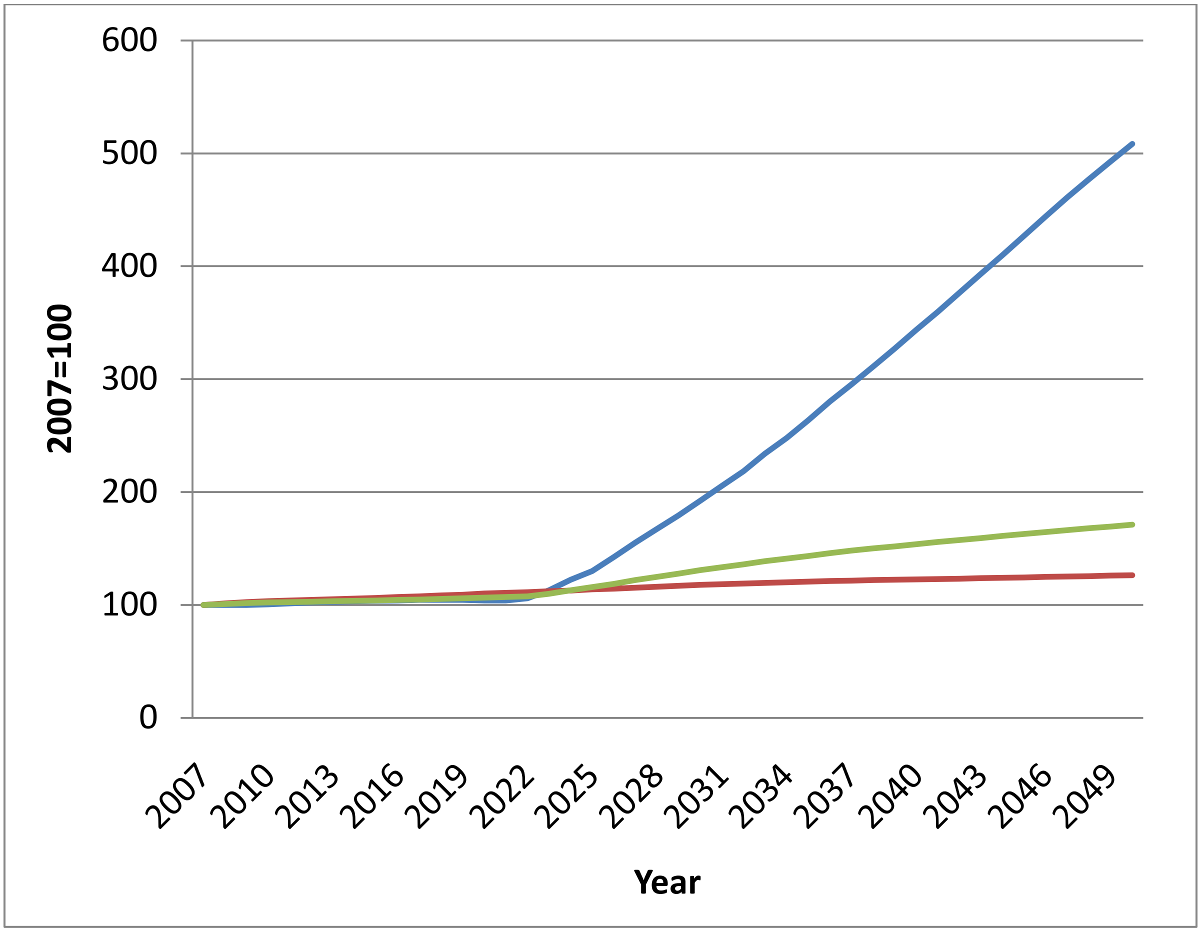


(B)

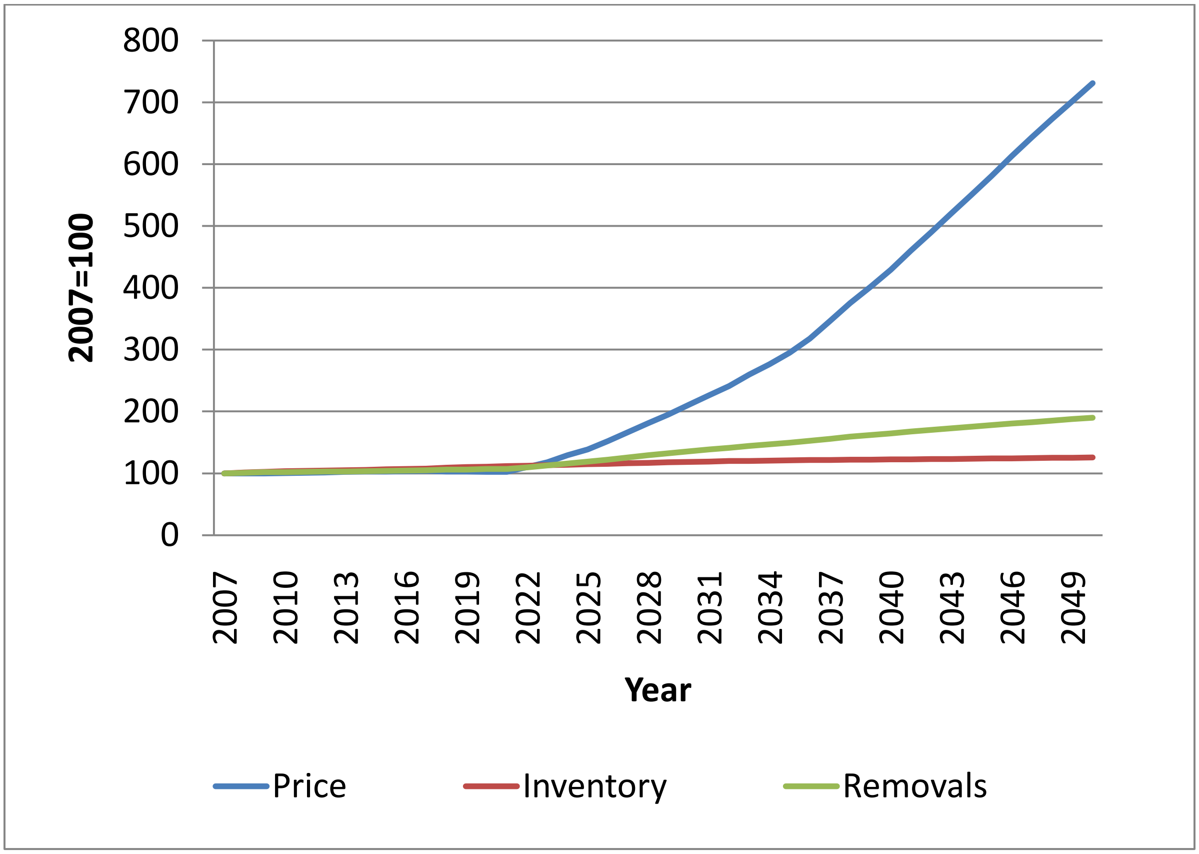


350
300
250
200
150
100
50
0
2007=100
2007
2010
2013
2016
2019
2022
2025
2028
2031
2034
2037
2040
2043
2046
2049
Year

(C)


600
500
400
300
200
100
0
2007=100
2007
2010
2013
2016
2019
2022
2025
2028
2031
2034
2037
2040
2043
2046
2049
Year

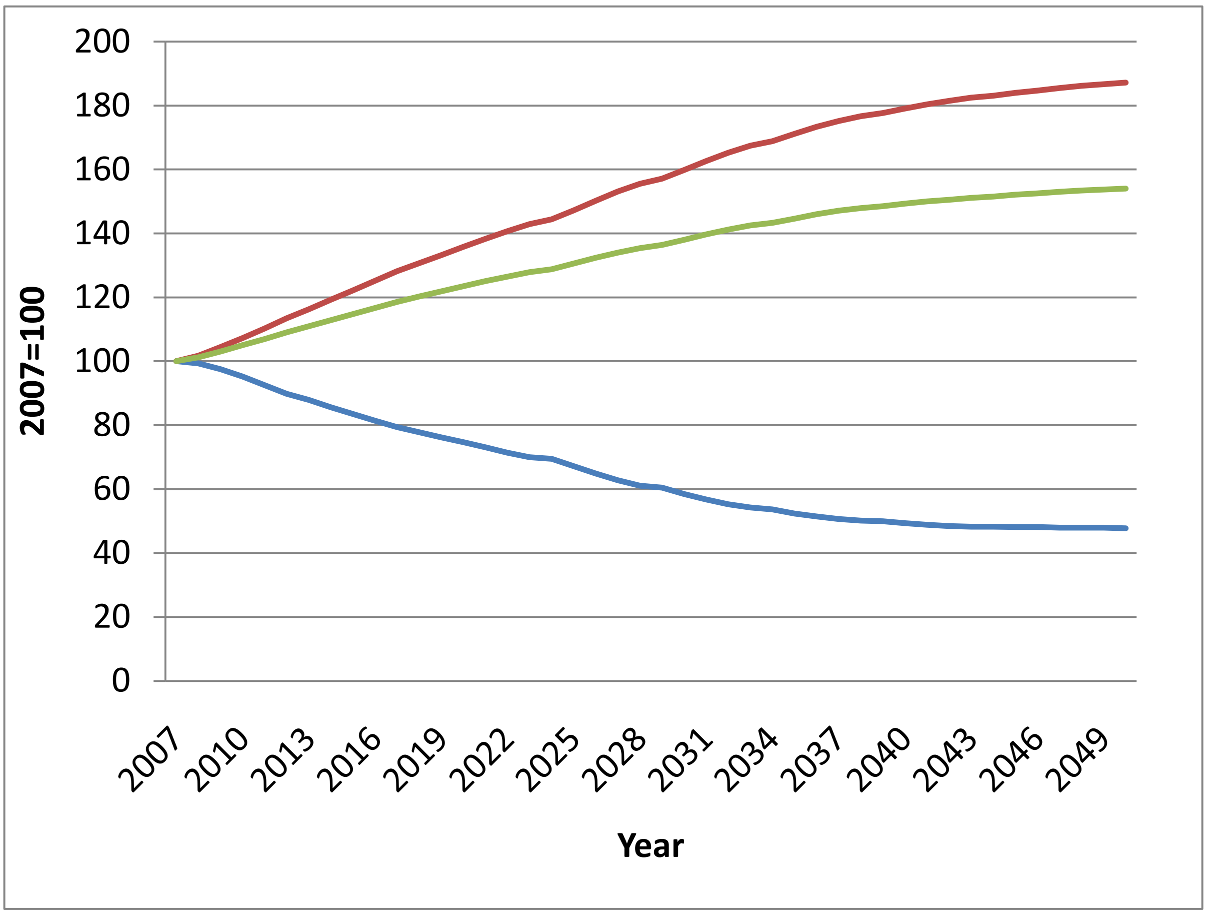
(D)



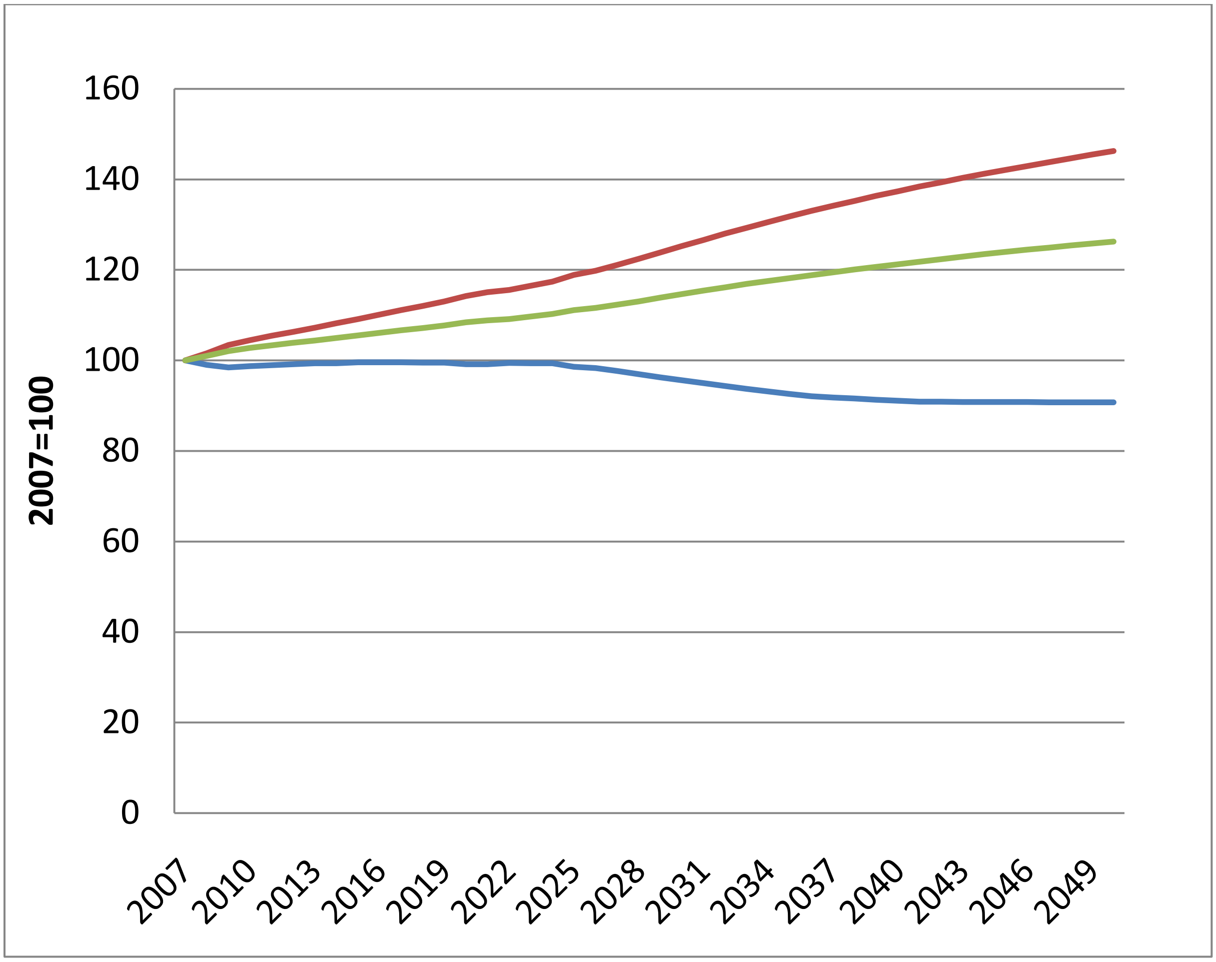
800
700
600
500
400
300
200
100
0
2007=100
2007
2010
2013
2016
2019
2022
2025
2028
2031
2034
2037
2040
2043
2046
2049
Year
Price
Inventory
Removals

Figure 10-15—Under a productivity strategy that is limited to pine plantations, market responses in price, inventory, and removals for southern (A) softwood and (B) hardwood sawtimber—both assuming moderate consumption of woody biomass for energy; and (C) softwood and (D) hardwood sawtimber—both assuming high consumption of woody biomass for energy.

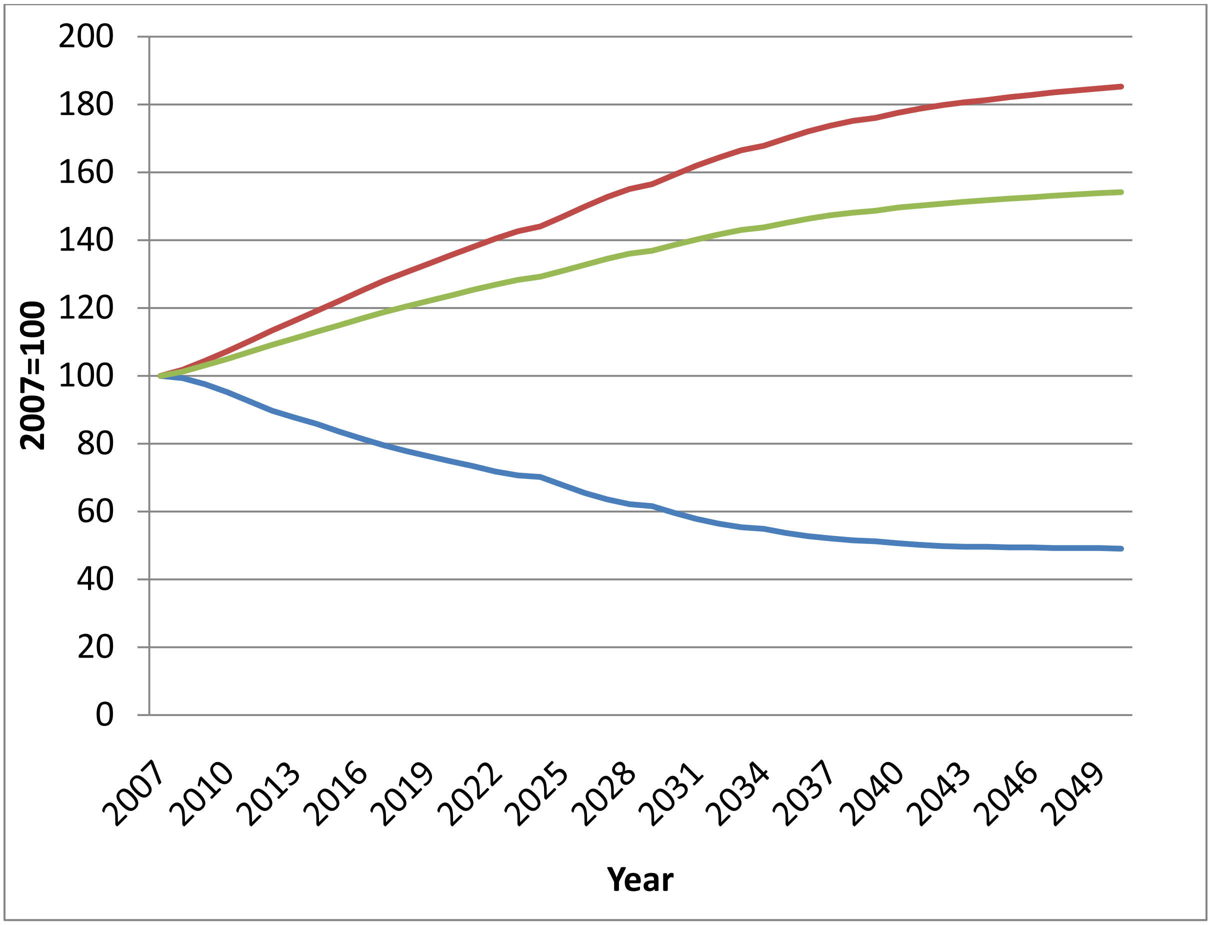
(A)



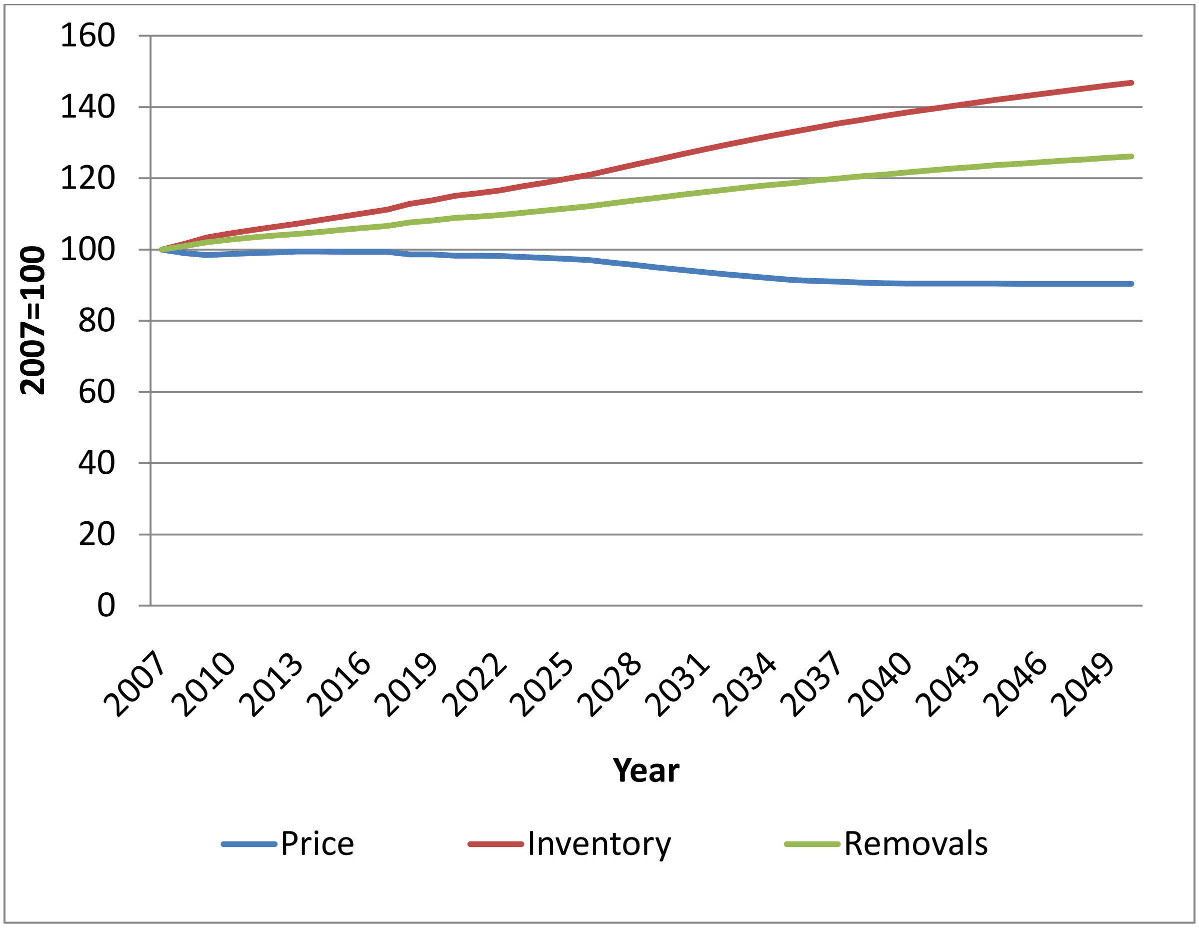
(B)


2007=100
160
140
120
100
80
60
40
20
0
2007
2010
2013
2016
2019
2022
2025
2028
2031
2034
2037
2040
2043
2046
2049

(C)


200
180
160
140
120
100
80
60
40
20
0
2007=100
2007
2010
2013
2016
2019
2022
2025
2028
2031
2034
2037
2040
2043
2046
2049
Year

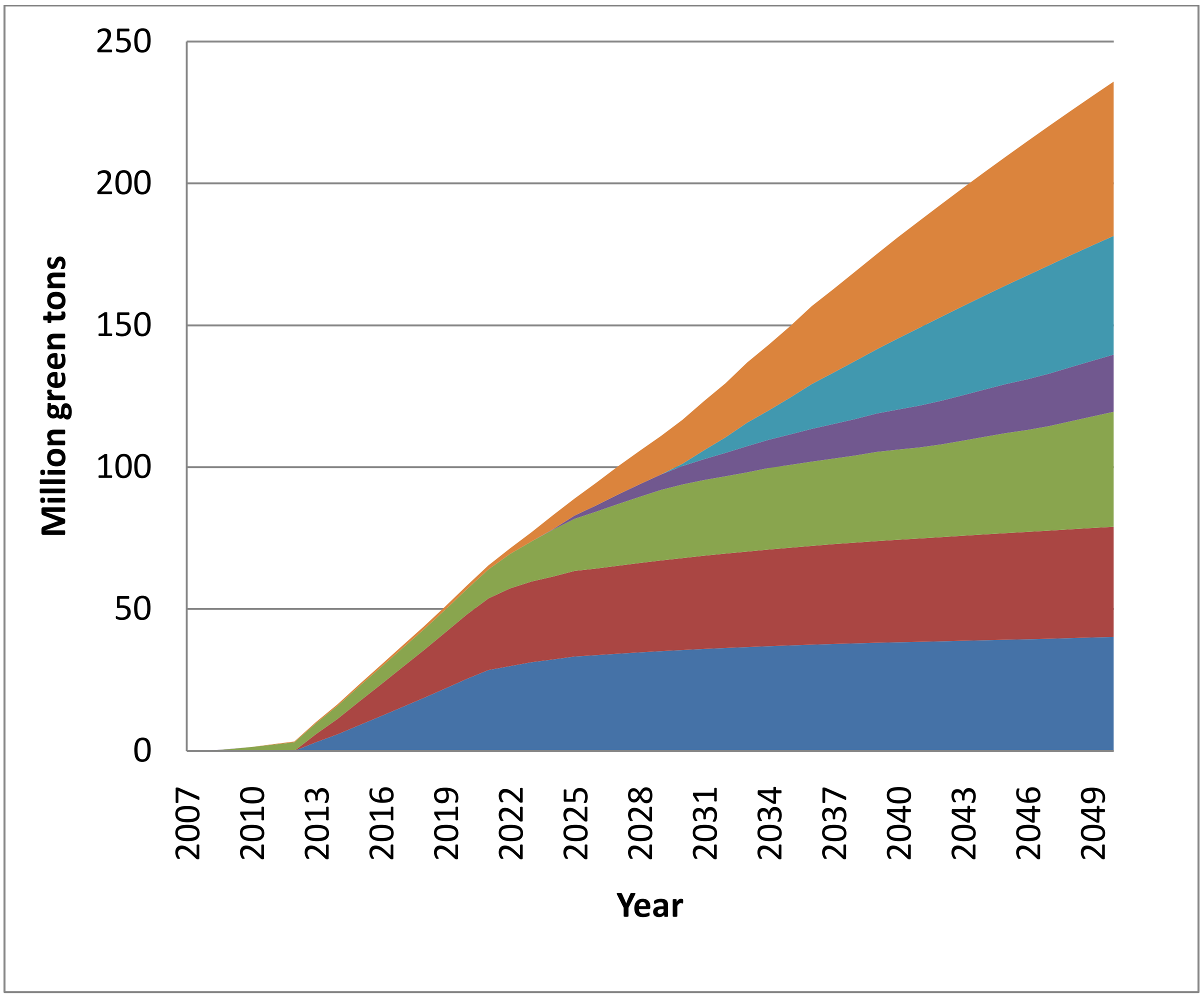
(D)



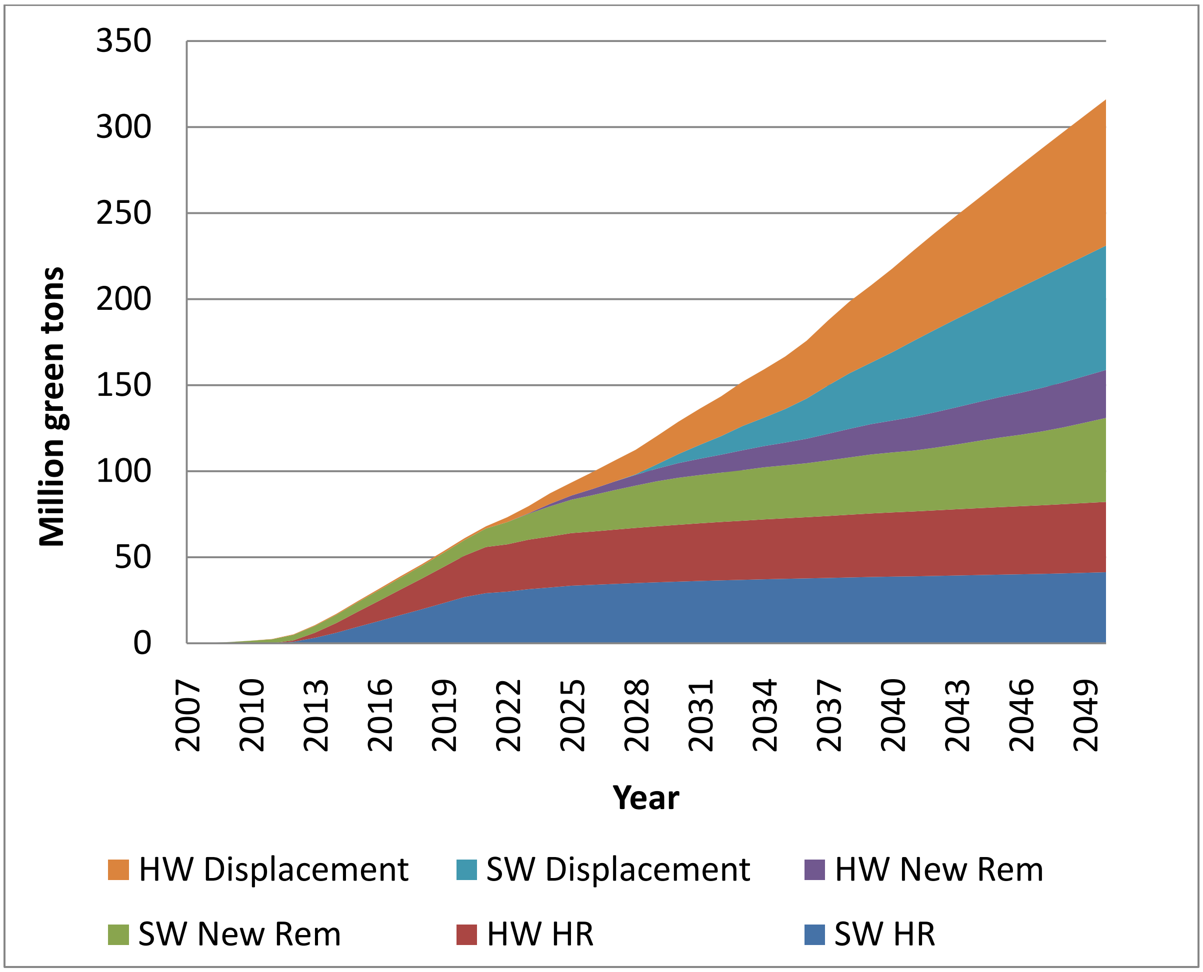
160
140
120
100
80
60
40
20
0
2007=100
2007
2010
2013
2016
2019
2022
2025
2028
2031
2034
2037
2040
2043
2046
2049
Year
Price
Inventory
Removals

Figure 10-16—Under a productivity strategy that is limited to pine plantations, feedstock composition in the South, assuming (A) moderate and (B) high consumption of woody biomass for energy.

(A)

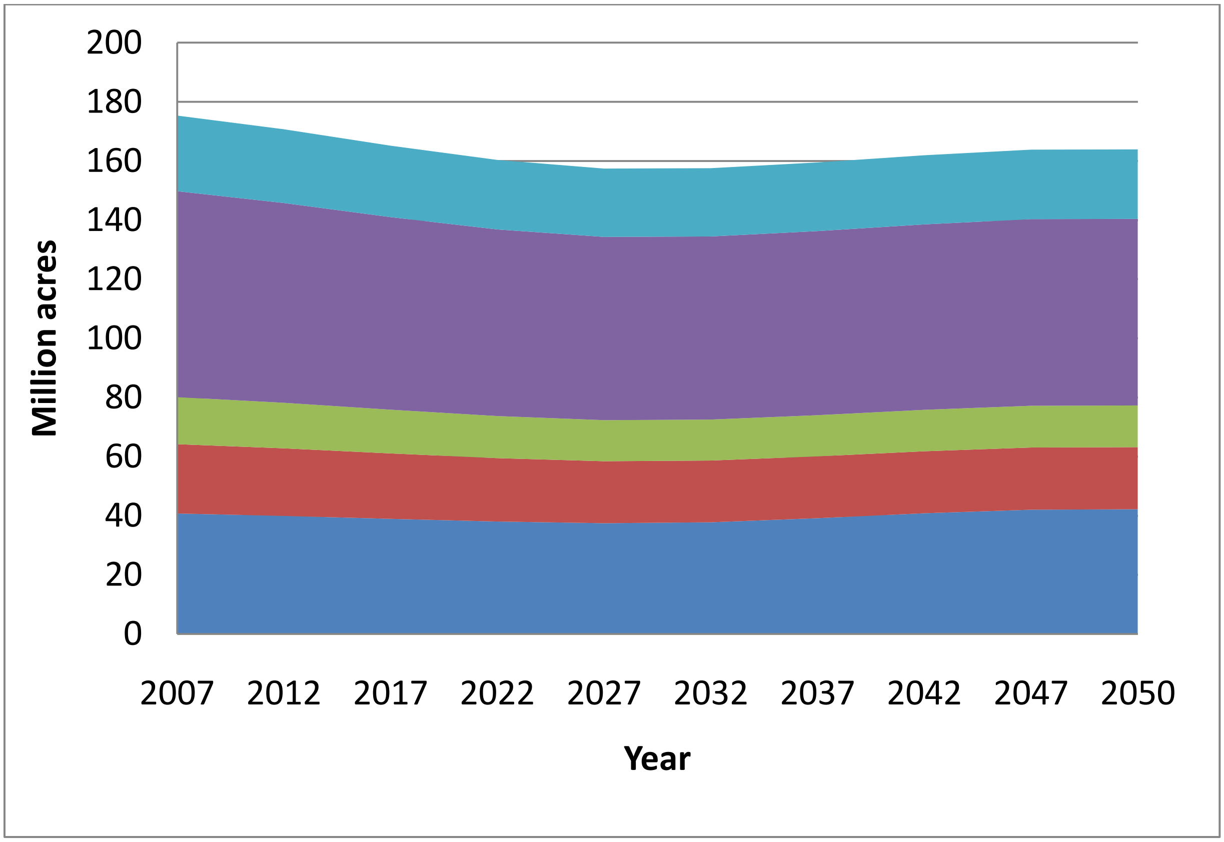


(B)



350
300
250
200
150
100
50
0
Million green tons
2007
2010
2013
2016
2019
2022
2025
2028
2031
2034
2037
2040
2043
2046
2049
Year
HW Displacement
SW Displacement
HW New Rem
SW New Rem
HW HR
SW HR

Figure 10-17—Under a productivity strategy that is limited to pine plantations, forest acreage change in the South, assuming (A) moderate and (B) high consumption of woody biomass for energy.
(A)



(B)

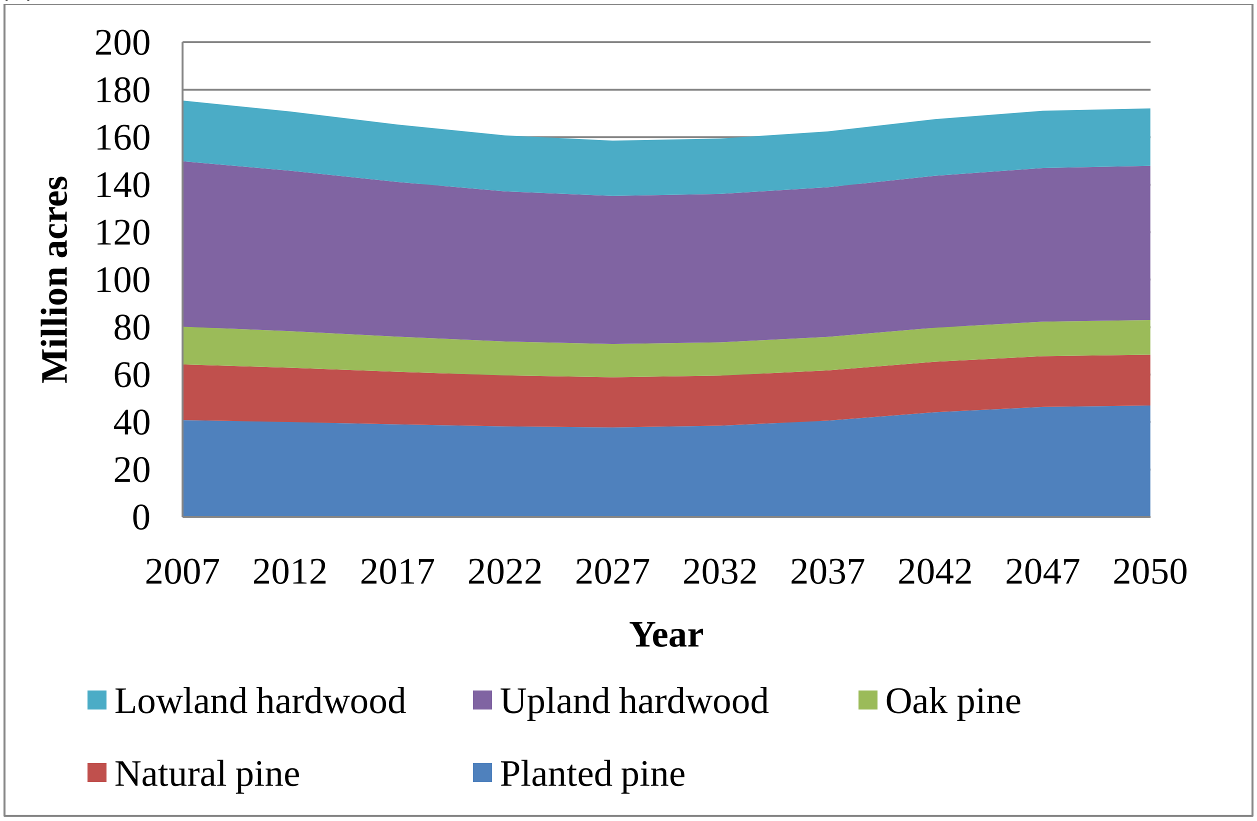
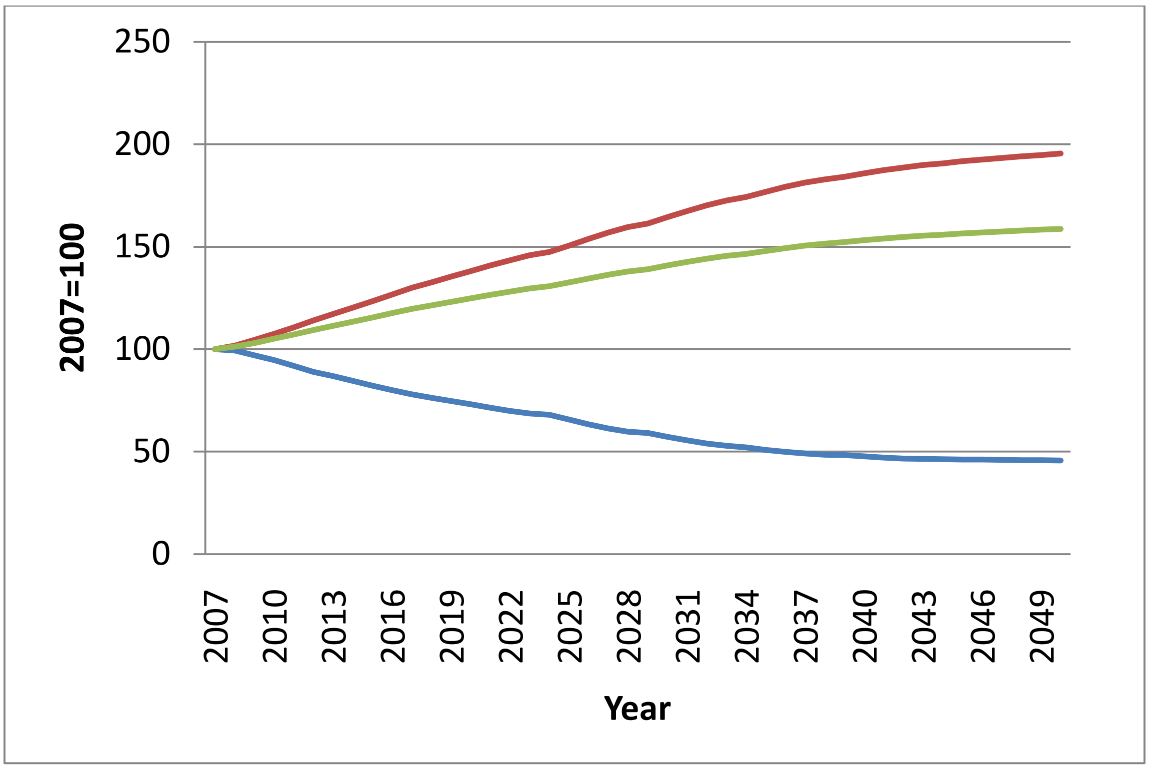
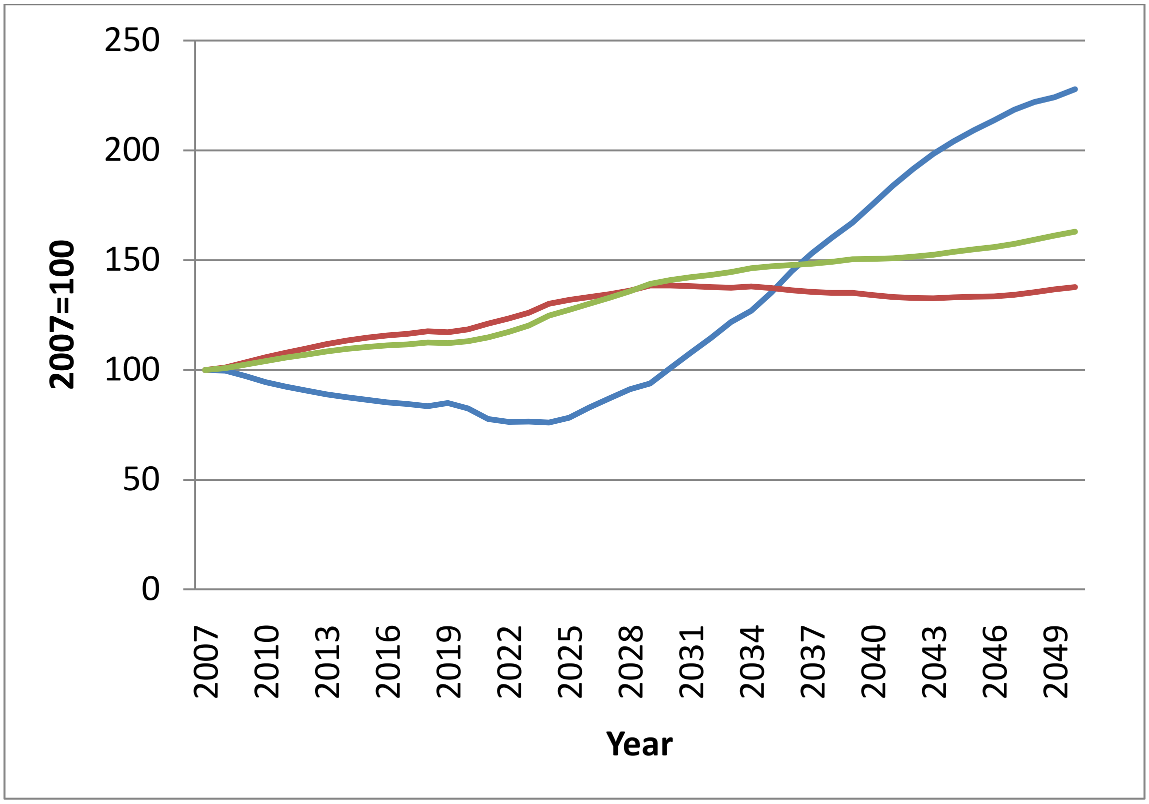

200
180
160
140
120
100
80
60
40
20
0
Million acres
2007
2012
2017
2022
2027
2032
2037
2042
2047
2050
Year
Lowland hardwood
Upland hardwood
Oak pine
Natural pine
Planted pine

Figure 10-18—Under a productivity strategy that extends to all forest management types, market responses in price, inventory, and removals for southern (A) softwood sawtimber and (B) other softwoods—both assuming moderate consumption of woody biomass for energy; and (C) softwood sawtimber and (D) other softwoods—both assuming high consumption of woody biomass for energy.

(A)

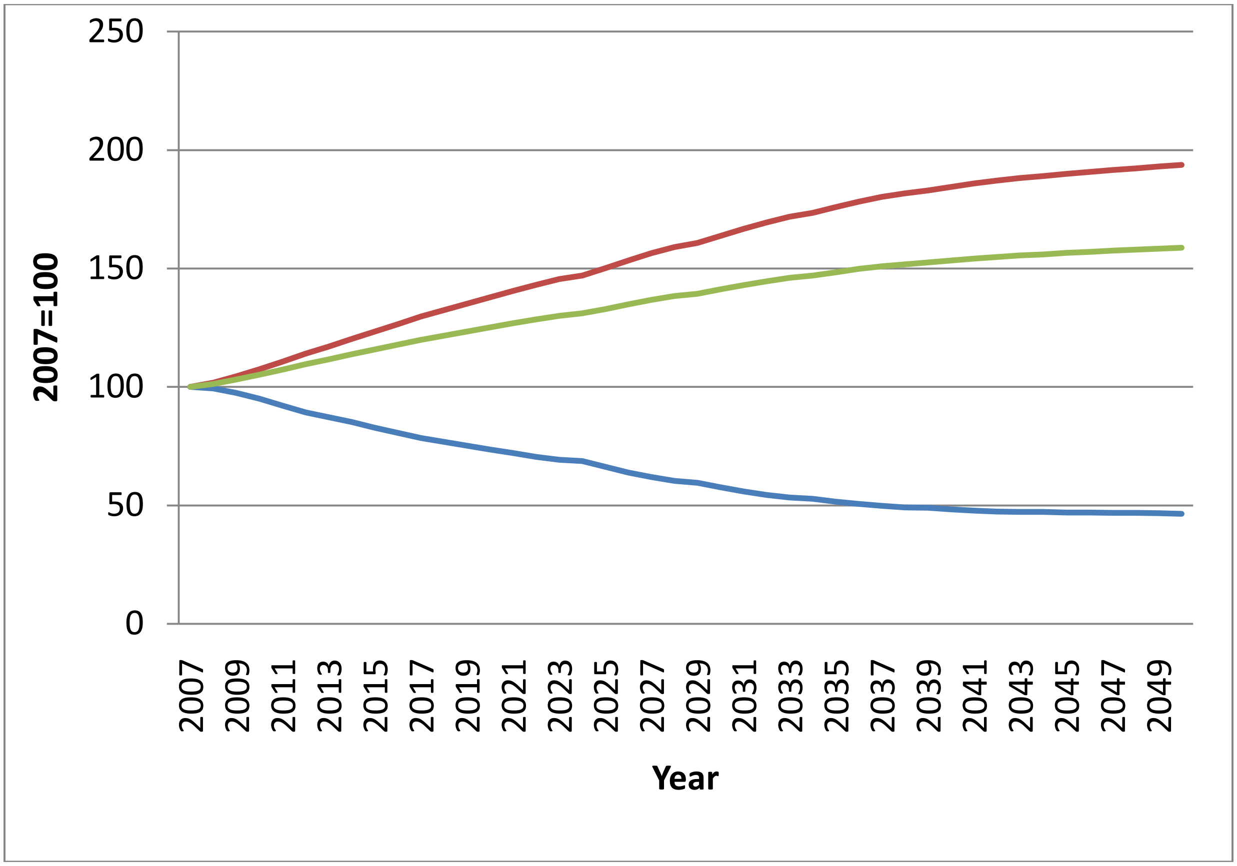


(B)



250
200
150
100
50
0
2007=100
2007
2010
2013
2016
2019
2022
2025
2028
2031
2034
2037
2040
2043
2046
2049
Year

(C)



250
200
150
100
50
0
2007=100
2007
2009
2011
2013
2015
2017
2019
2021
2023
2025
2027
2029
2031
2033
2035
2037
2039
2041
2043
2045
2047
2049
Year

(D)

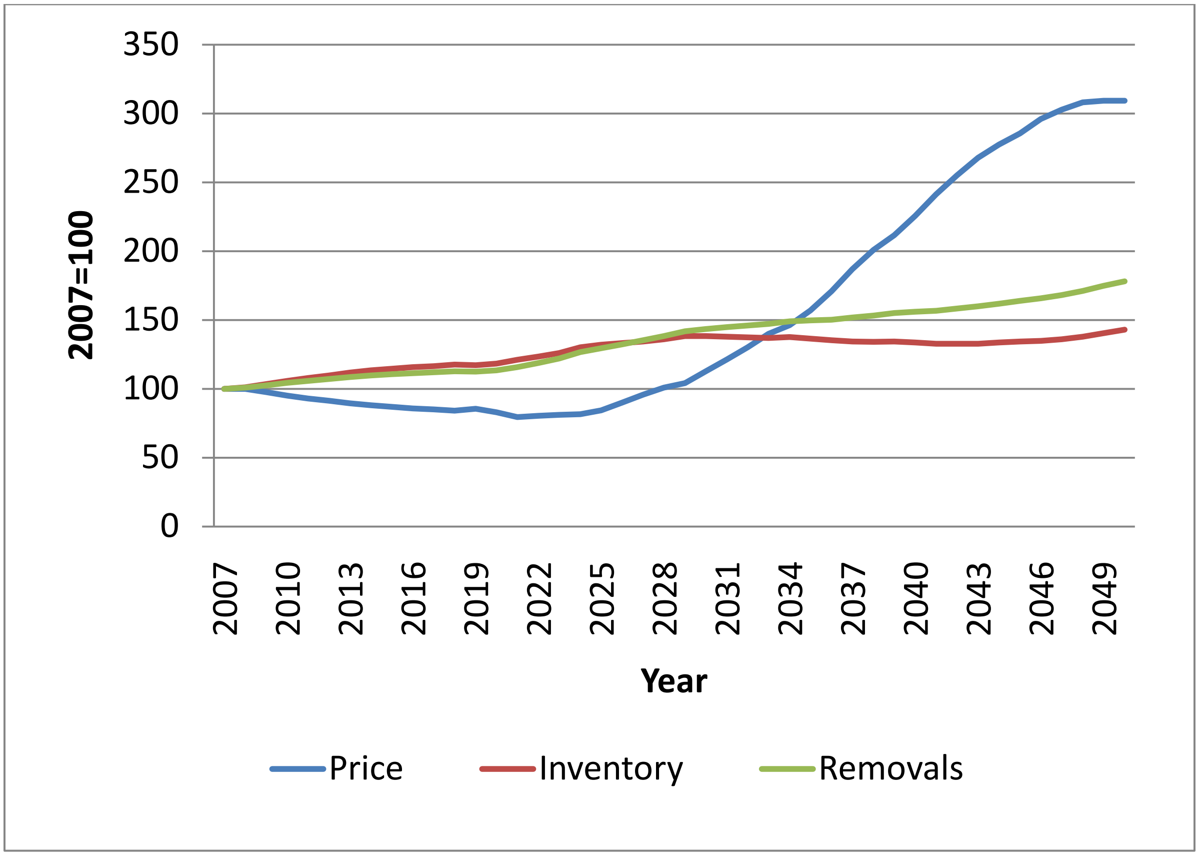
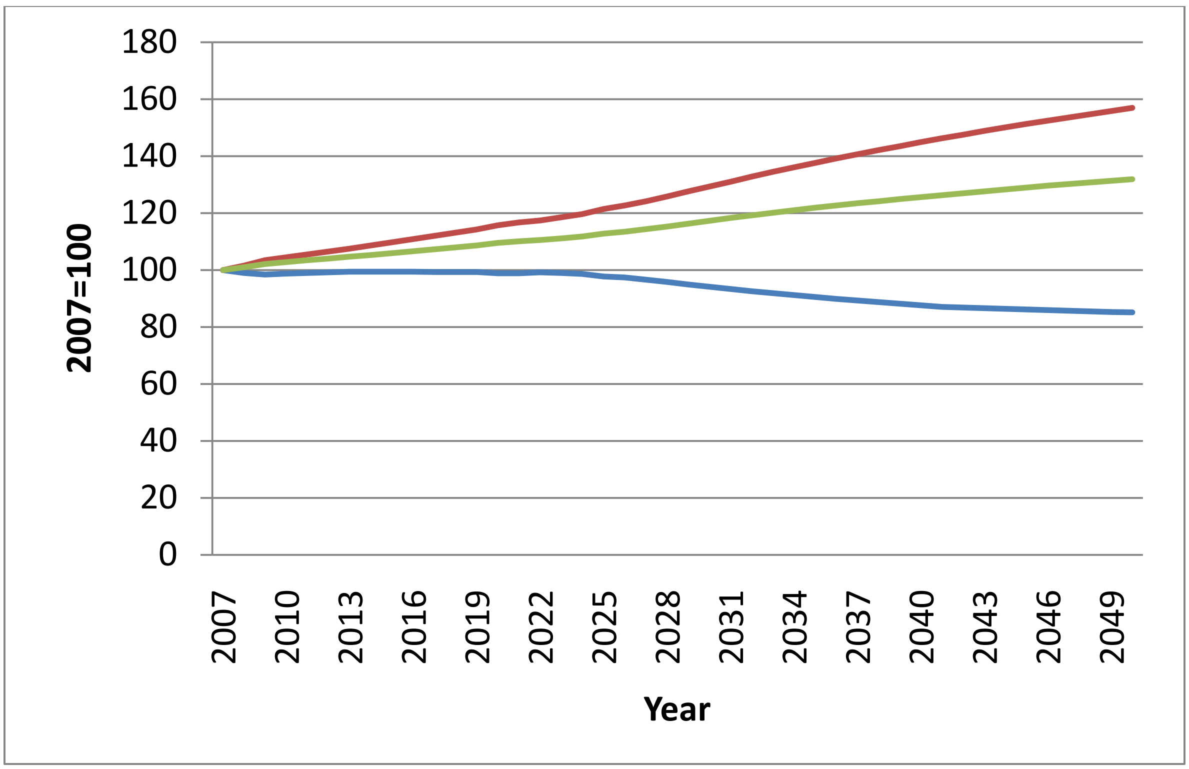
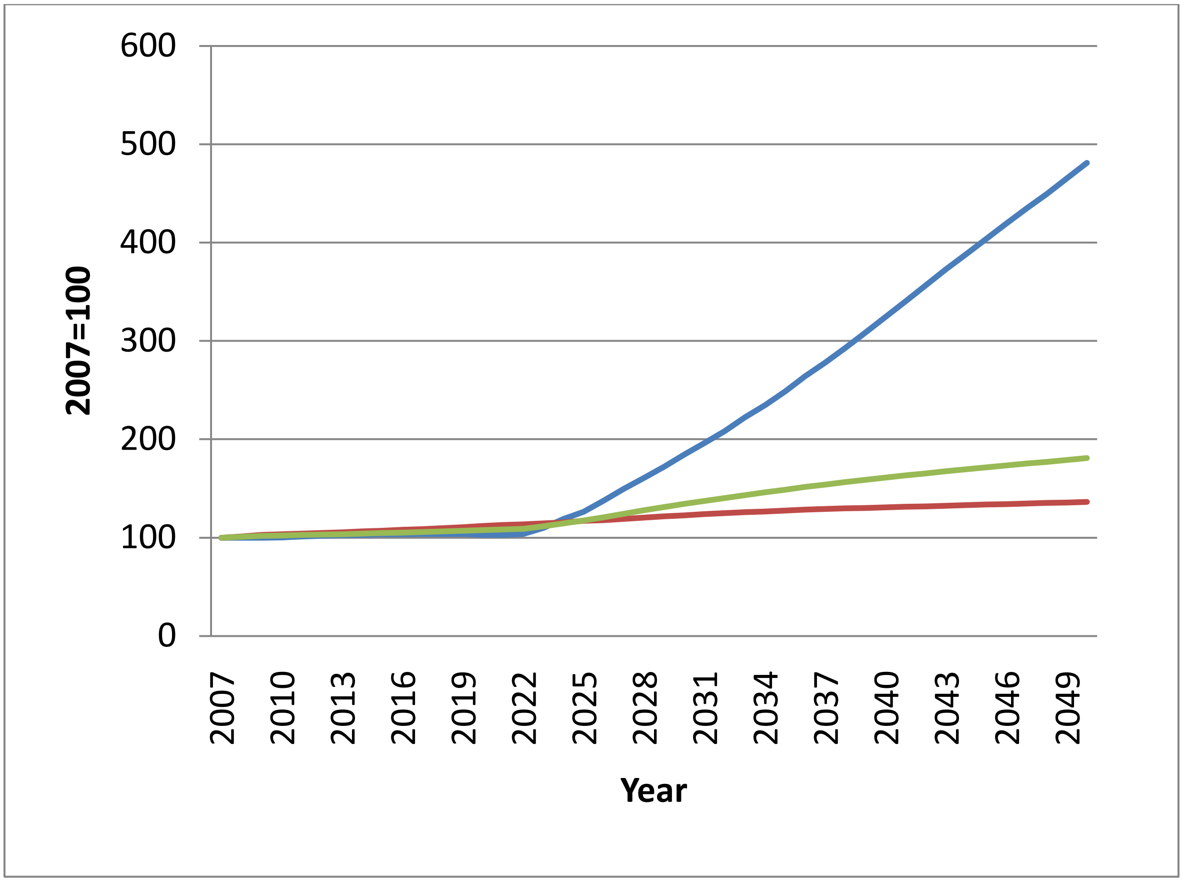

350
300
250
200
150
100
50
0
2007=100
2007
2010
2013
2016
2019
2022
2025
2028
2031
2034
2037
2040
2043
2046
2049
Year
Price
Inventory
Removals

Figure 10-19—Under a productivity strategy that extends to all forest management types, market responses in price, inventory, and removals for southern (A) hardwood sawtimber and (B) other hardwoods—both assuming moderate consumption of woody biomass for energy; and (C) hardwood sawtimber and (D) other hardwoods—both assuming high consumption of woody biomass for energy.

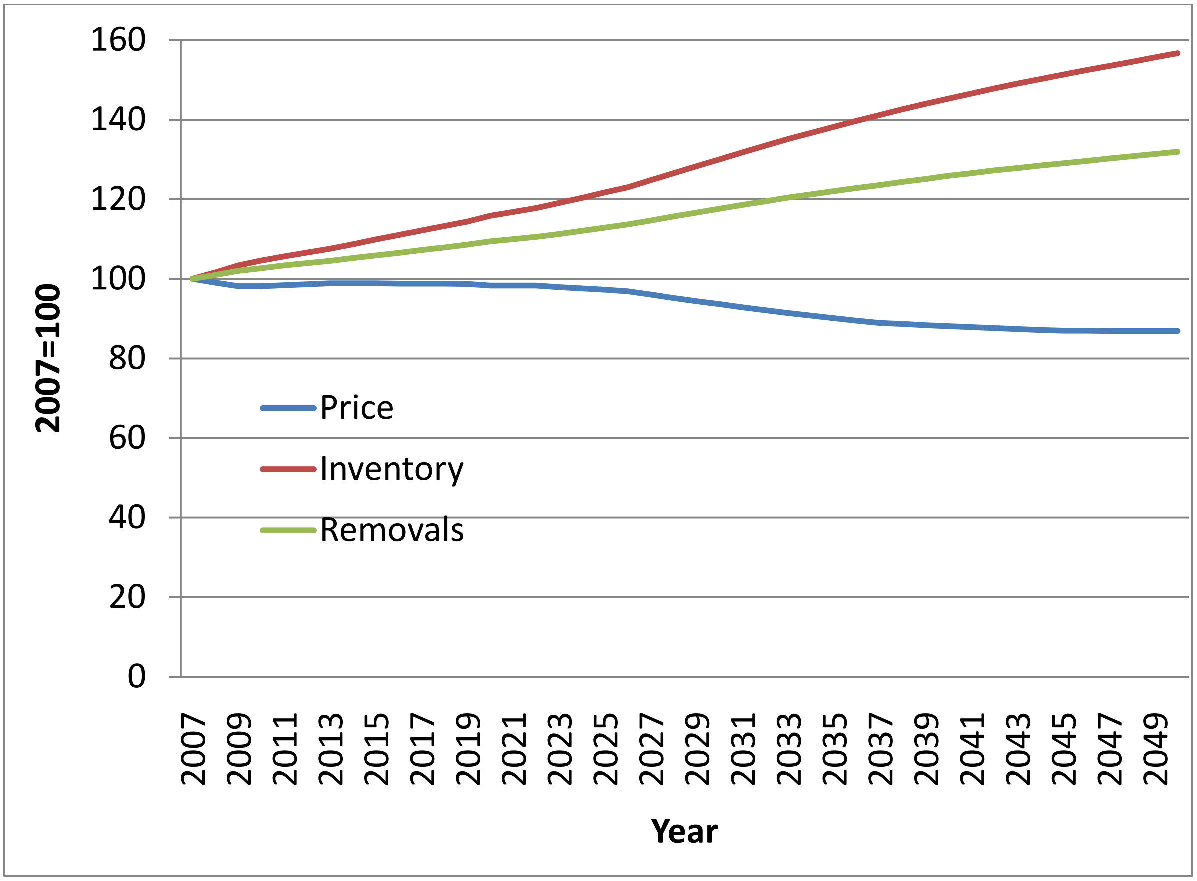
(A)



(B)


600
500
400
300
200
100
0
2007=100
2007
2010
2013
2016
2019
2022
2025
2028
2031
2034
2037
2040
2043
2046
2049
Year

(C)



160
140
120
100
80
60
40
20
0
2007=100
Price
Inventory
Removals
2007
2009
2011
2013
2015
2017
2019
2021
2023
2025
2027
2029
2031
2033
2035
2037
2039
2041
2043
2045
2047
2049
Year

(D)

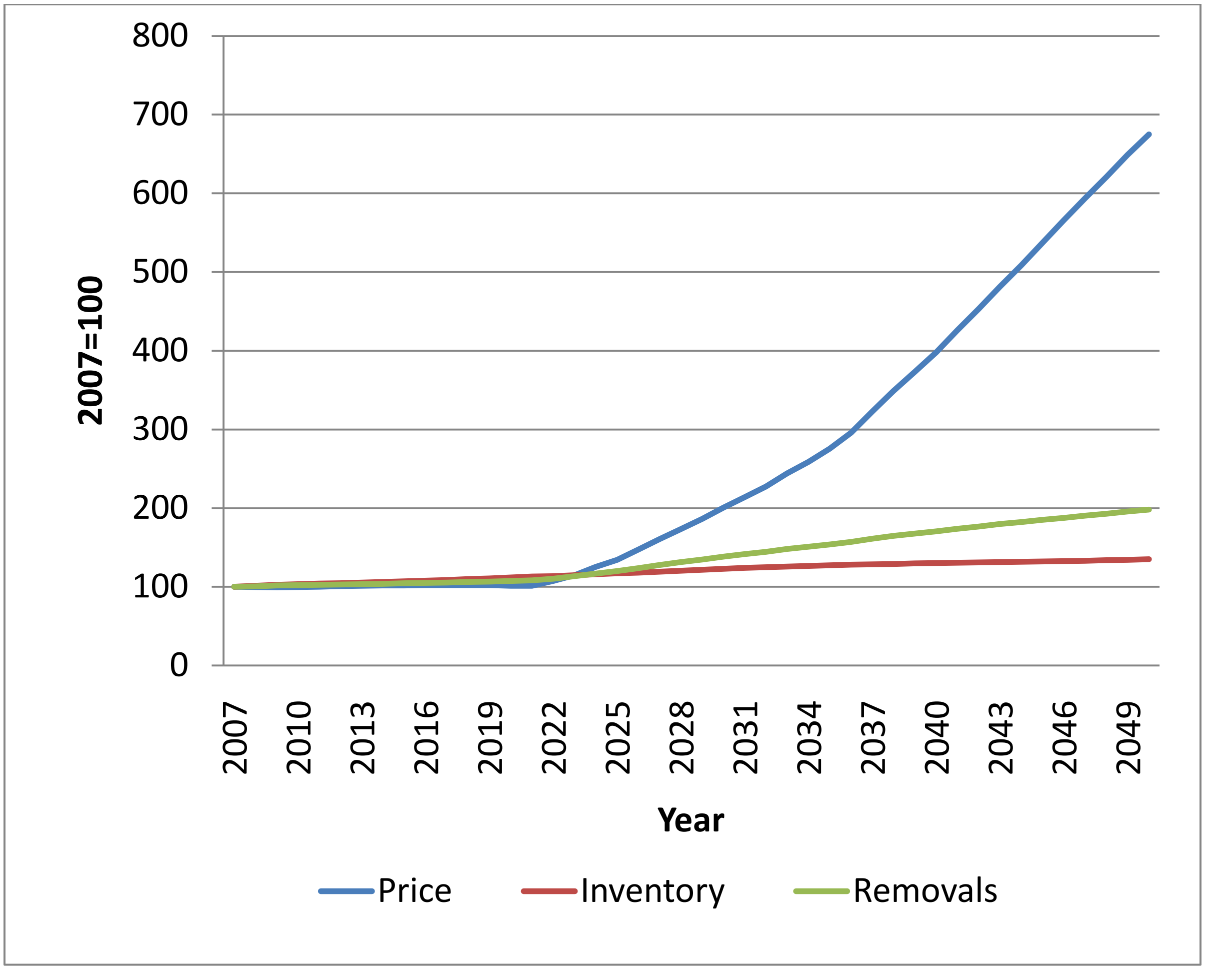
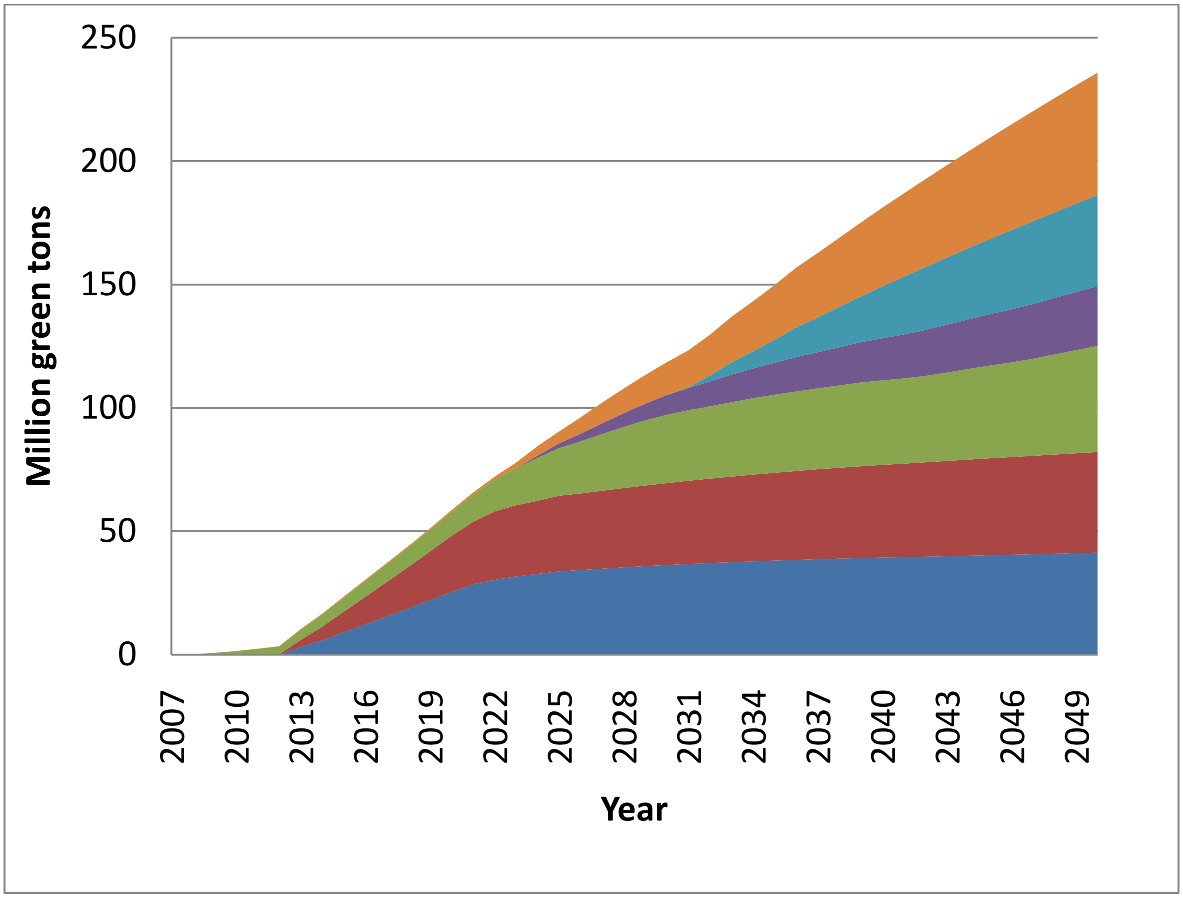
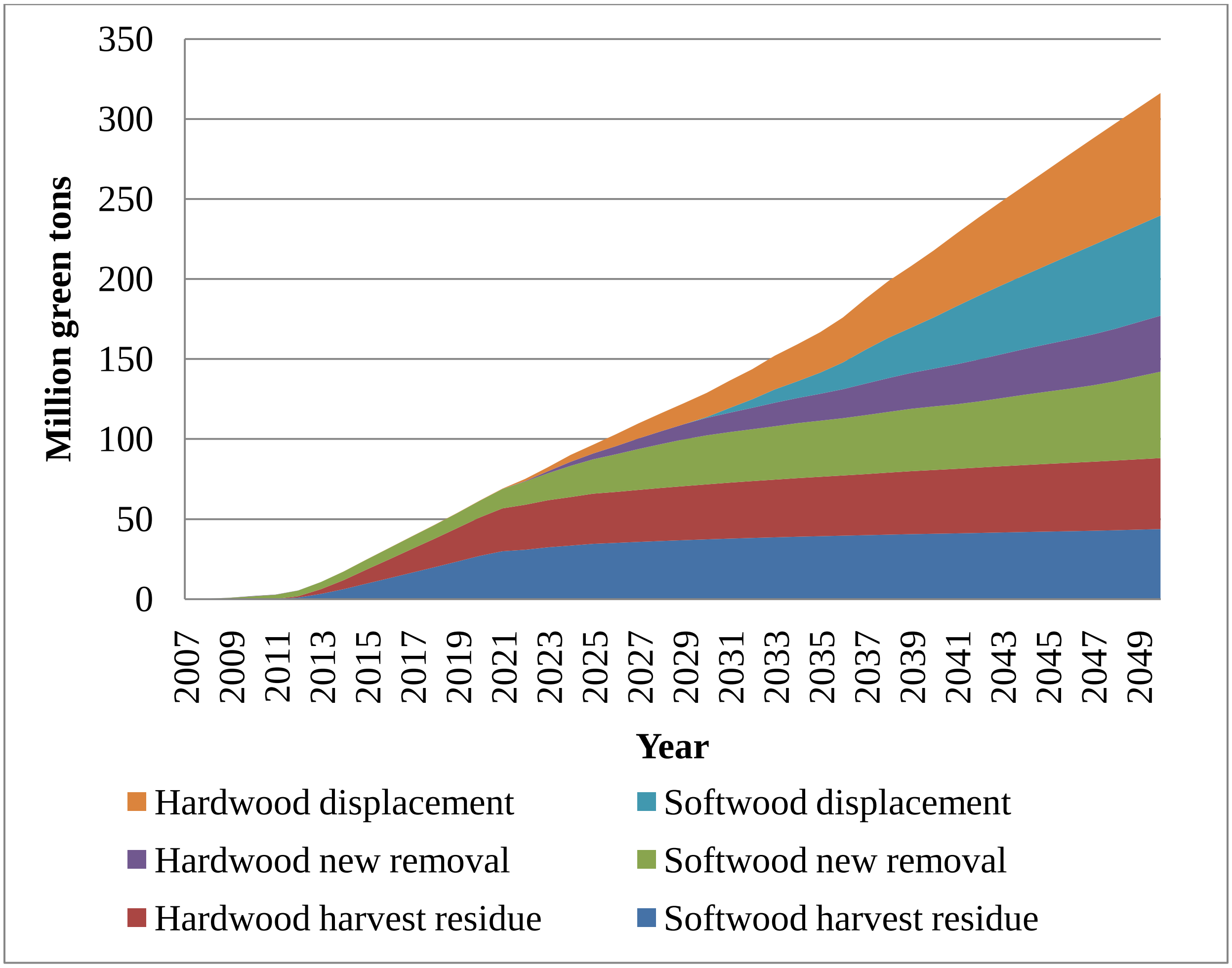

800
700
600
500
400
300
200
100
0
2007=100
2007
2010
2013
2016
2019
2022
2025
2028
2031
2034
2037
2040
2043
2046
2049
Year
Price
Inventory
Removals

Figure 10-20—Under a productivity strategy that extends to all forest management types, feedstock composition in the South, assuming (A) moderate and (B) high consumption of woody biomass for energy.

(A)



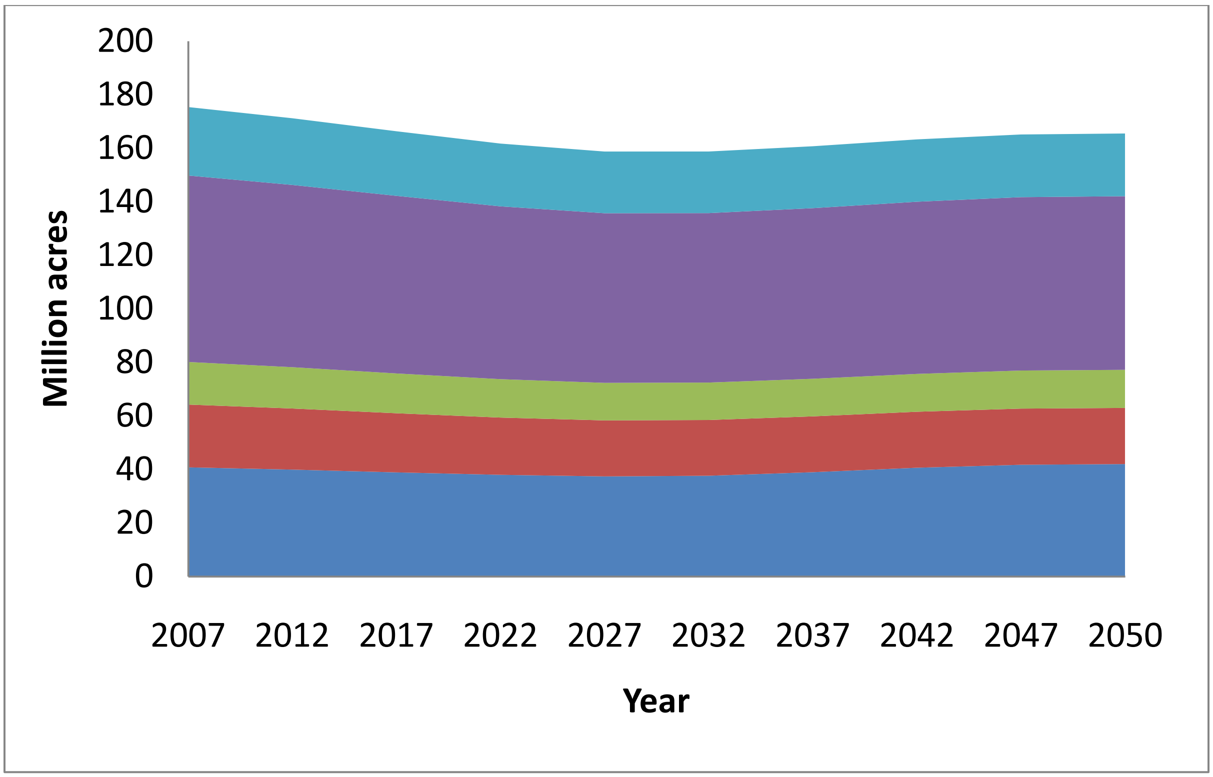
(B)



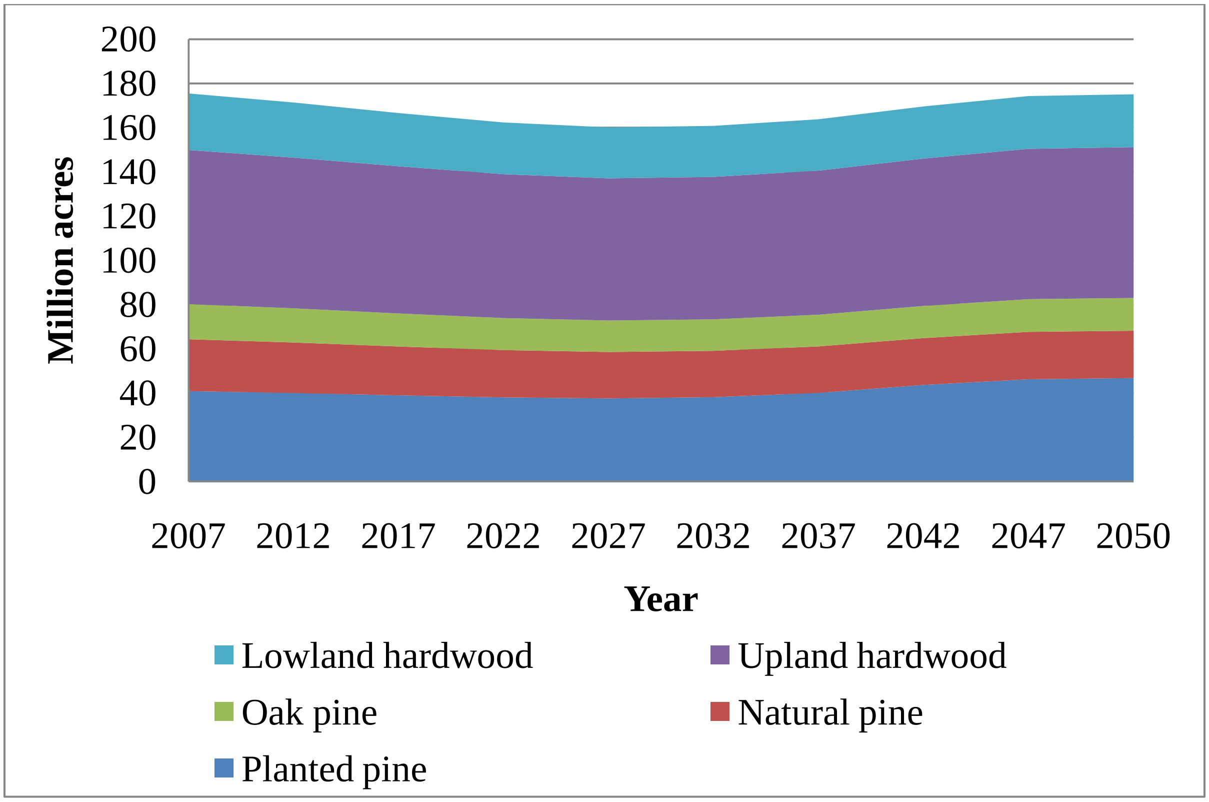
Million green tons
350
300
250
200
150
100
50
0
2007
2009
2011
2013
2015
2017
2019
2021
2023
2025
2027
2029
2031
2033
2035
2037
2039
2041
2043
2045
2047
2049
Year
Hardwood displacement
Softwood displacement
Hardwood new removal
Softwood new removal
Hardwood harvest residue
Softwood harvest residue

Figure 10-21—Under a productivity strategy that extends to all forest management types, private forest acreage change in the South, assuming (A) moderate and (B) high consumption of woody biomass for energy.

(A)



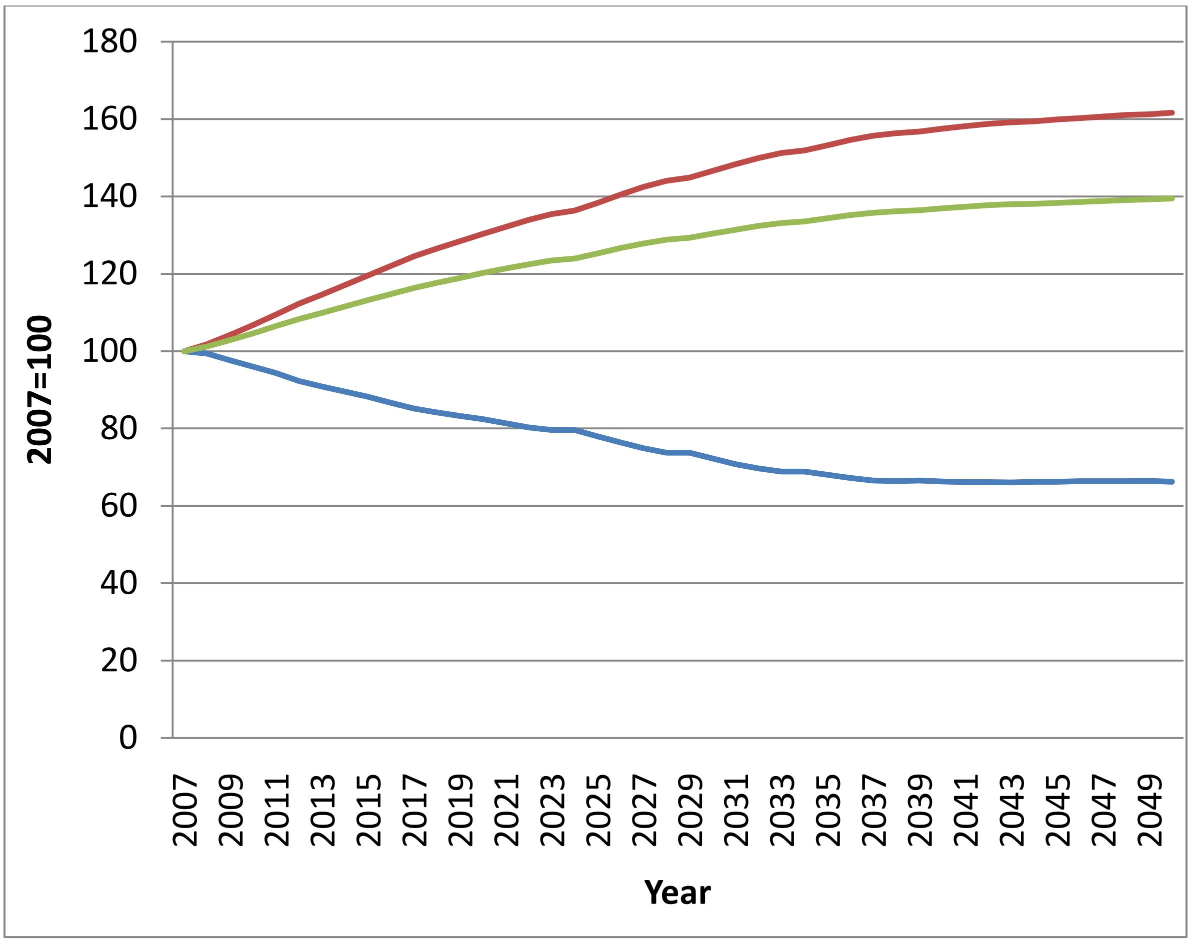
(B)



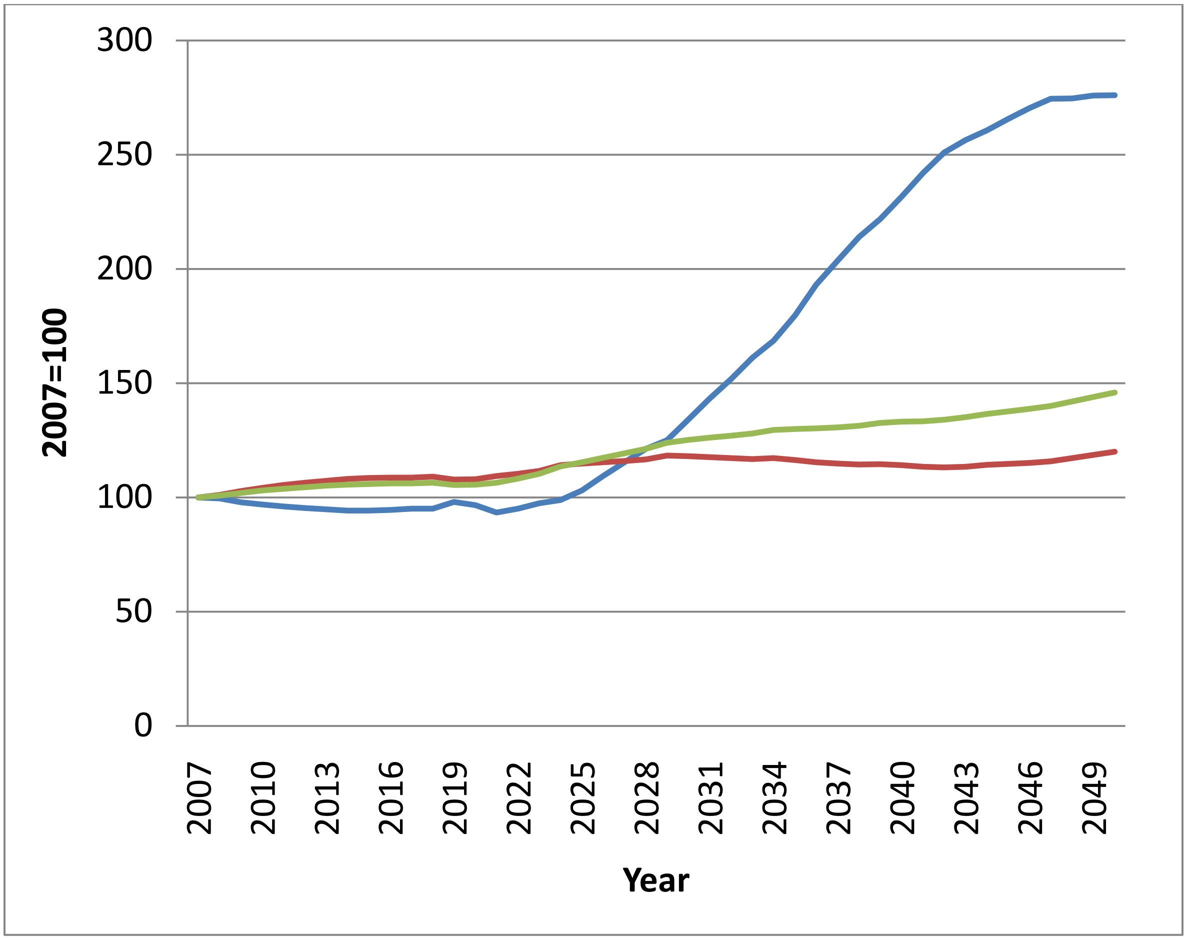
Million acres
200
180
160
140
120
100
80
60
40
20
0
2007
2012
2017
2022
2027
2032
2037
2042
2047
2050
Year
Lowland hardwood
Upland hardwood
Oak pine
Natural pine
Planted pine

Figure 10-22—Under a low-productivity strategy, market responses in price, inventory, and removals for southern (A) softwood sawtimber (B) other softwoods, (C) hardwood sawtimber, and (D) other hardwoods—all assuming moderate consumption of woody biomass for energy.

(A)

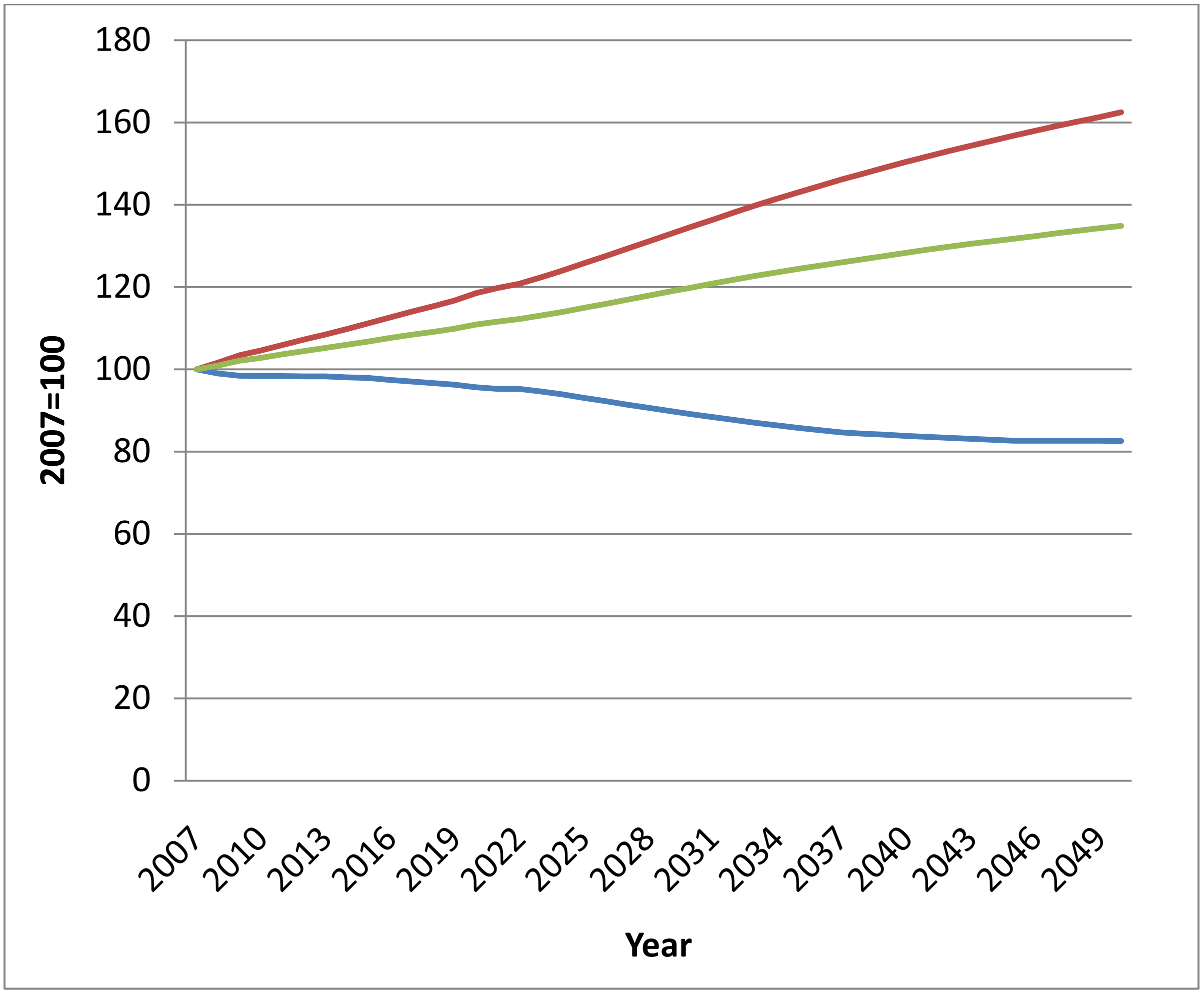


(B)



300
250
200
150
100
50
0
2007=100
2007
2010
2013
2016
2019
2022
2025
2028
2031
2034
2037
2040
2043
2046
2049
Year

(C)



180
160
140
120
100
80
60
40
20
0
2007=100
2007
2010
2013
2016
2019
2022
2025
2028
2031
2034
2037
2040
2043
2046
2049
Year

(D)

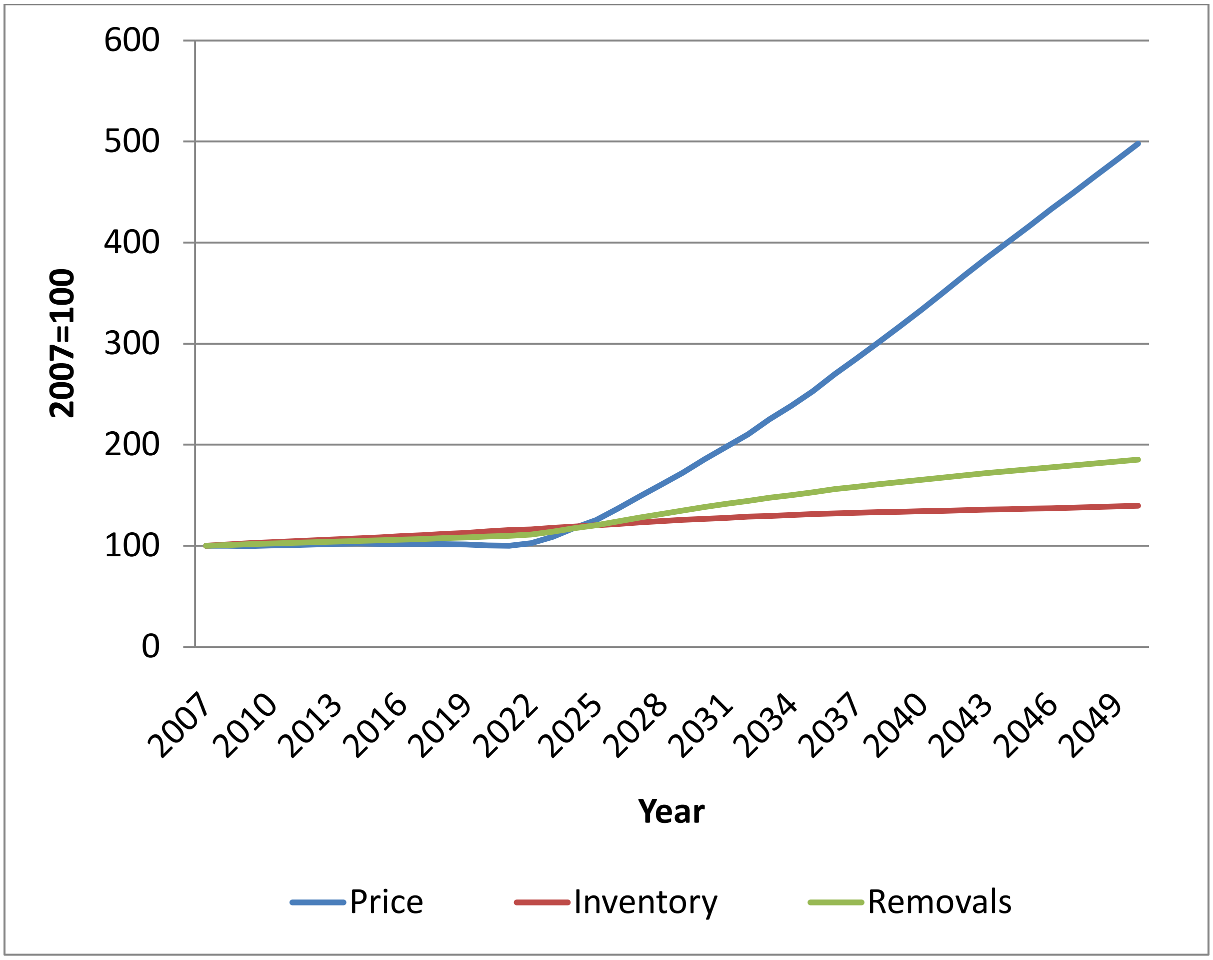
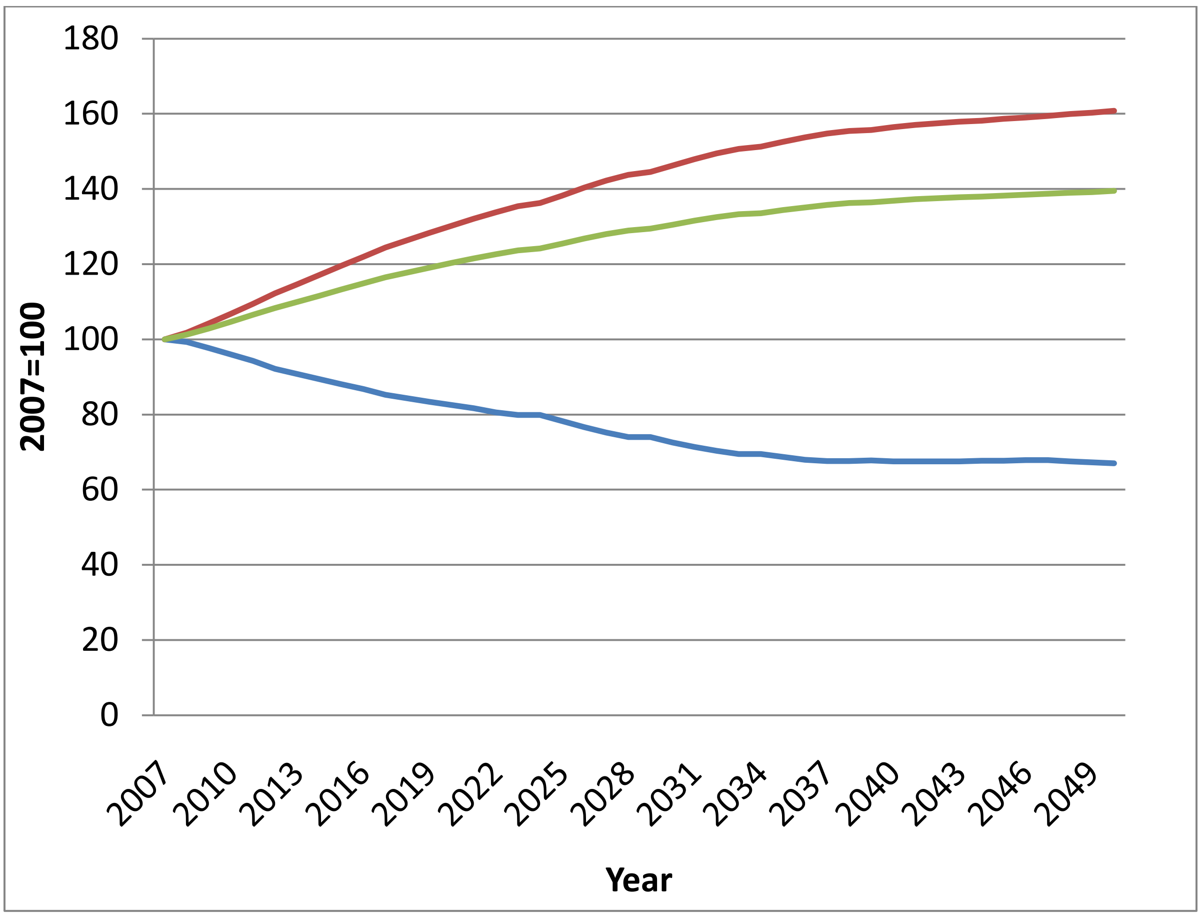
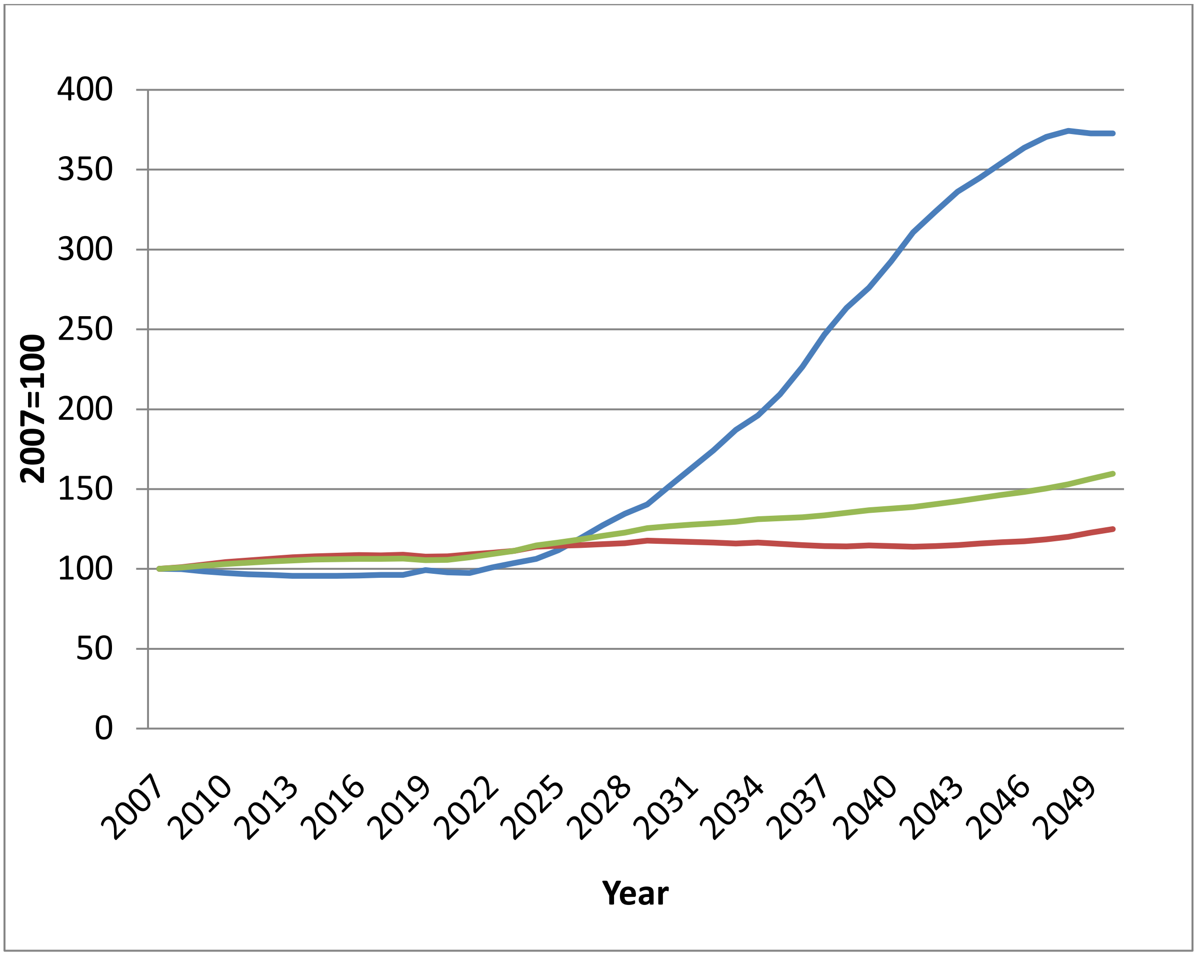

2007=100
600
500
400
300
200
100
0
2007
2010
2013
2016
2019
2022
2025
2028
2031
2034
2037
2040
2043
2046
2049
Year
Price
Inventory
Removals

Figure 10-23—Under a low-productivity strategy, market responses in price, inventory, and removals for southern (A) softwood sawtimber (B) other softwoods, (C) hardwood sawtimber, and (D) other hardwoods—all assuming moderate consumption of woody biomass for energy.

(A)

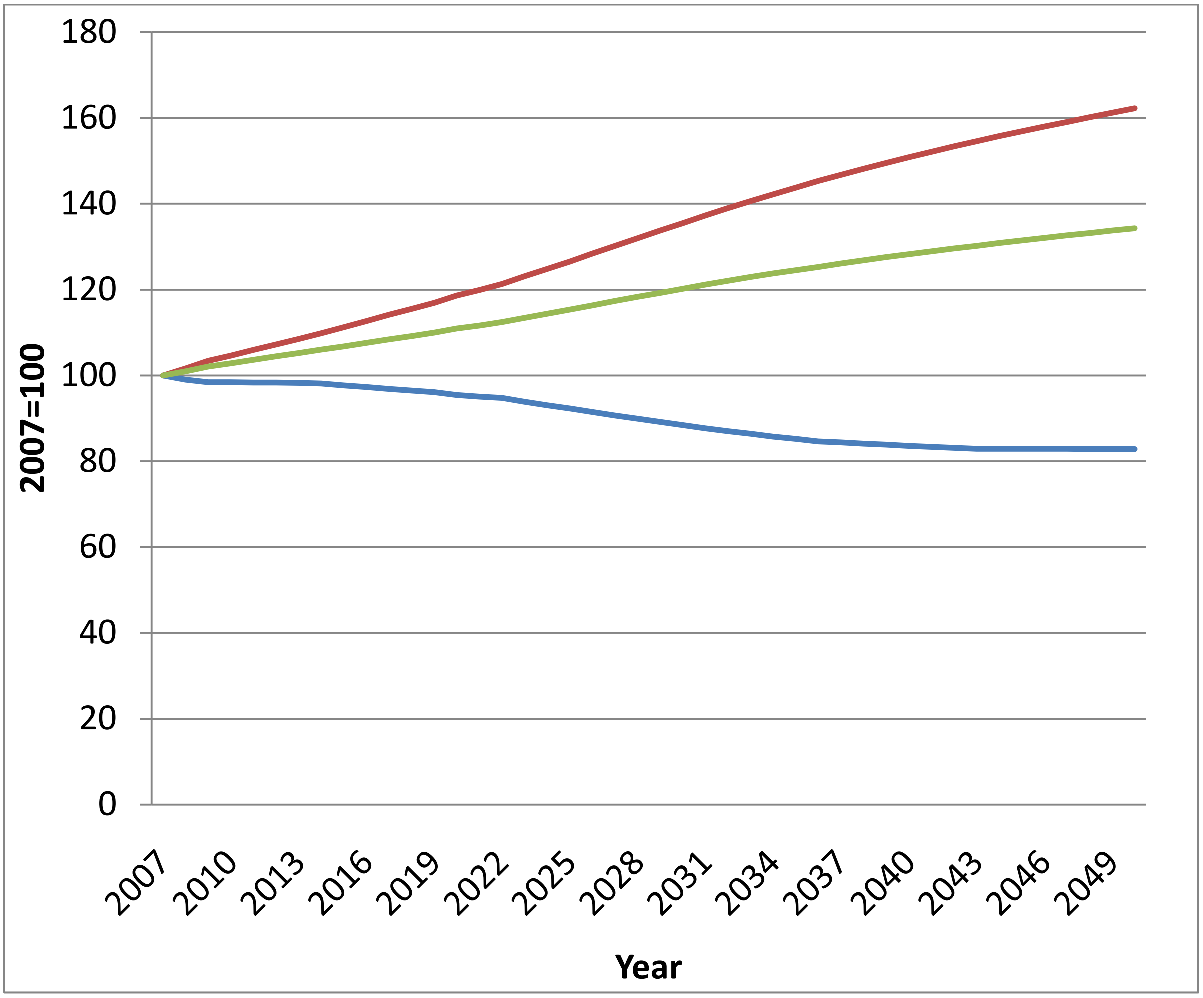


(B)

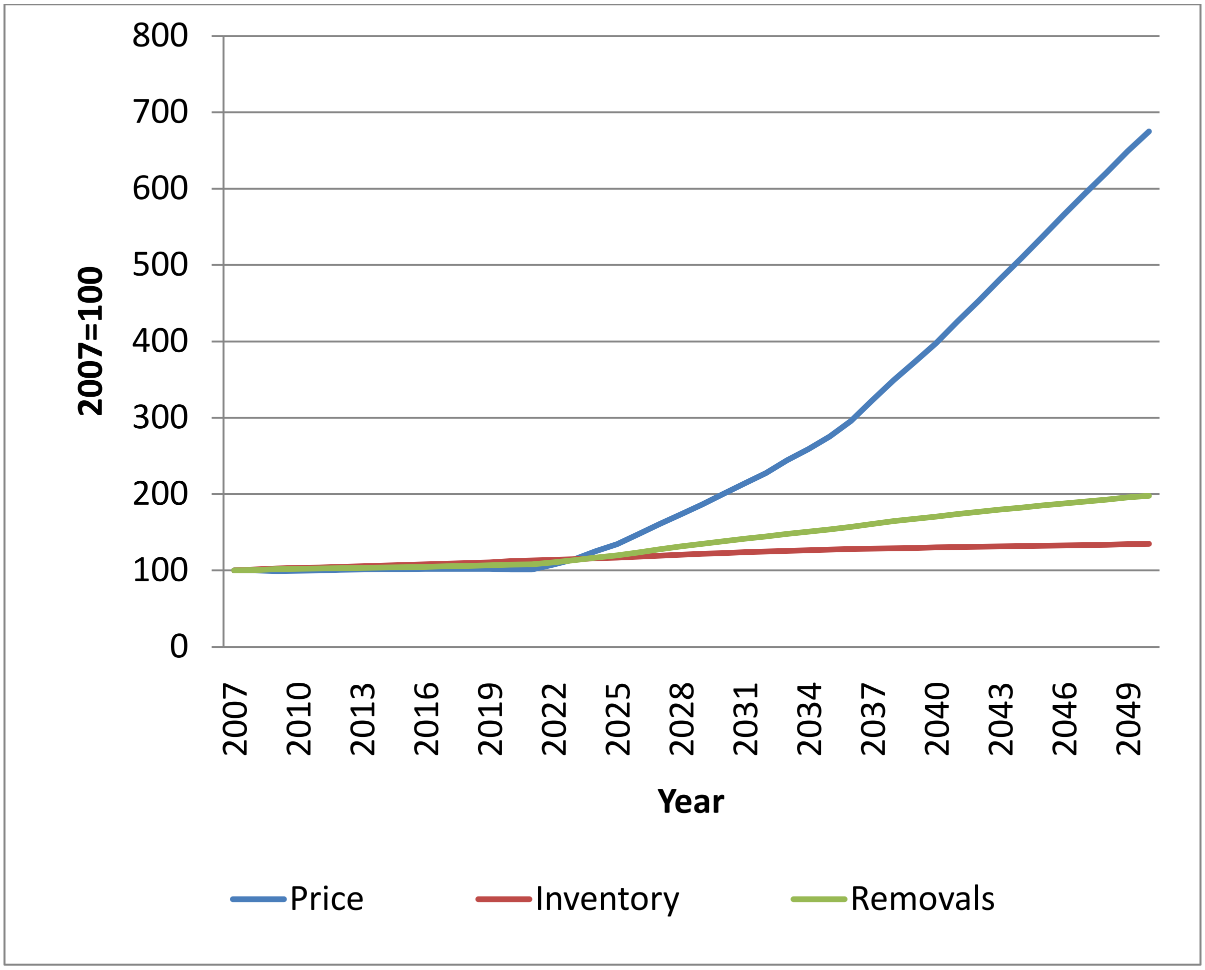


400
350
300
250
200
150
100
50
0
2007=100
2007
2010
2013
2016
2019
2022
2025
2028
2031
2034
2037
2040
2043
2046
2049
Year

(C)


180
160
140
120
100
80
60
40
20
0
2007=100
2007
2010
2013
2016
2019
2022
2025
2028
2031
2034
2037
2040
2043
2046
2049
Year

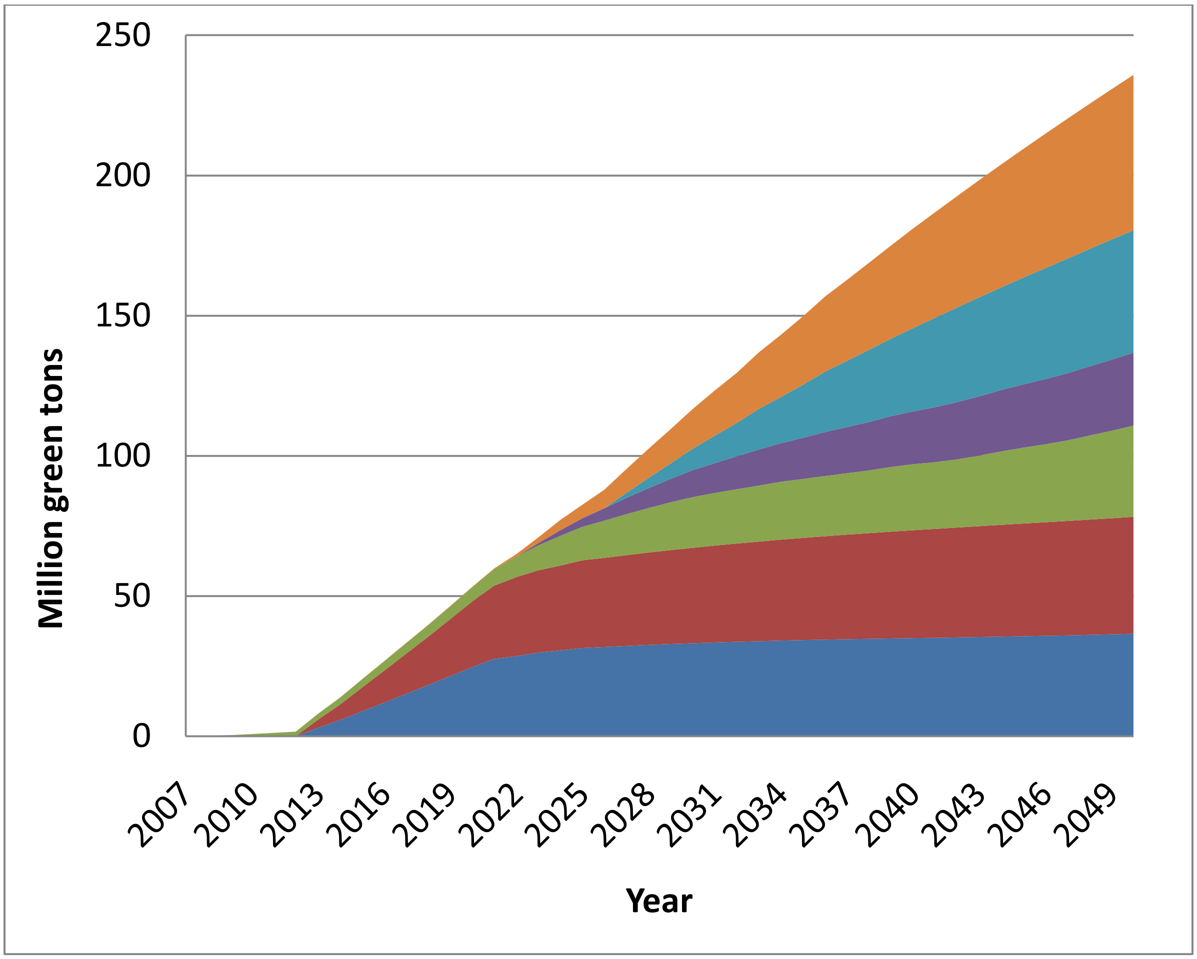
(D)



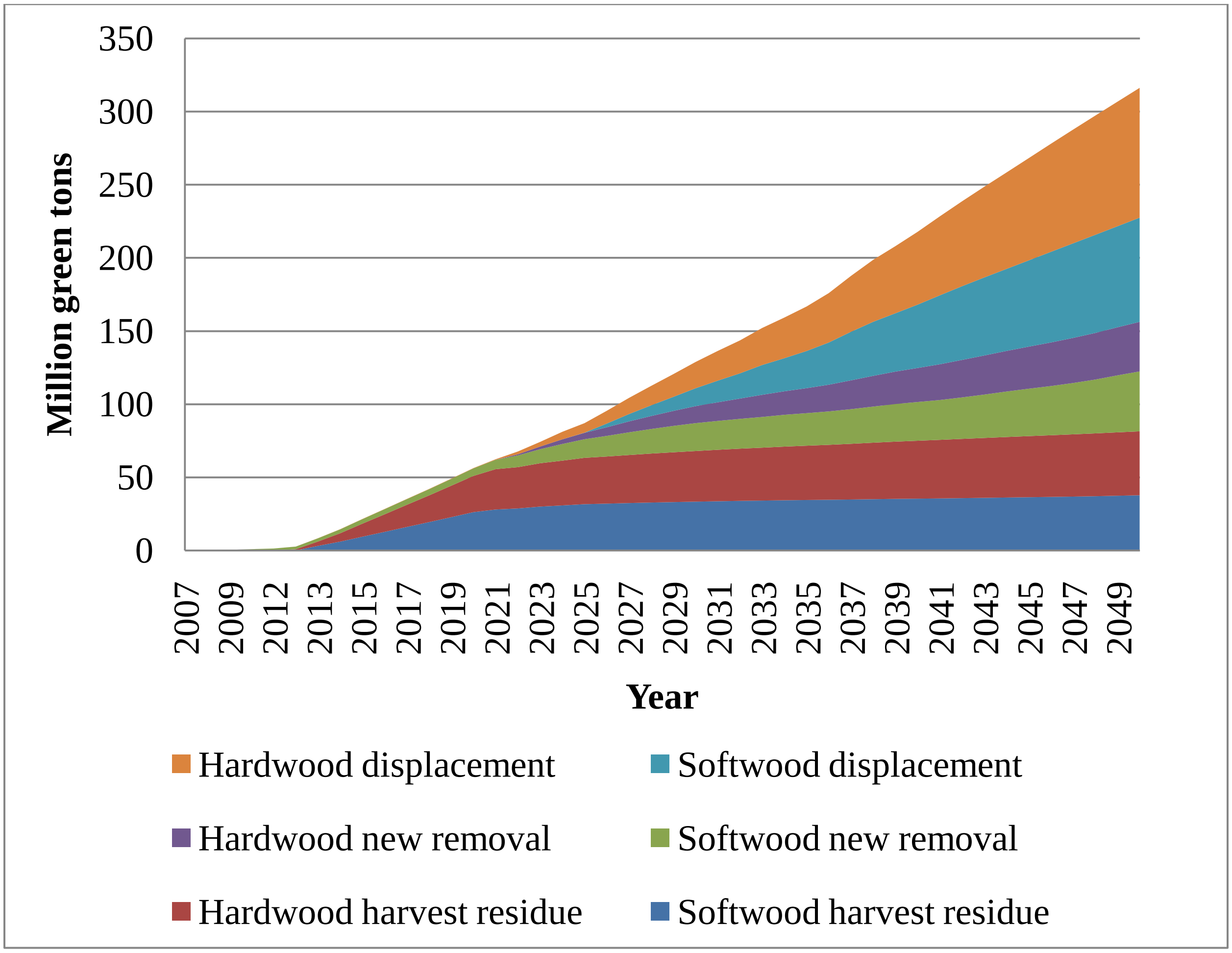
800
700
600
500
400
300
200
100
0
2007=100
2007
2010
2013
2016
2019
2022
2025
2028
2031
2034
2037
2040
2043
2046
2049
Year
Price
Inventory
Removals

Figure 10-24——Under a low-productivity strategy, feedstock composition in the South, assuming (A) moderate and (B) high consumption of woody biomass for energy.

(A)



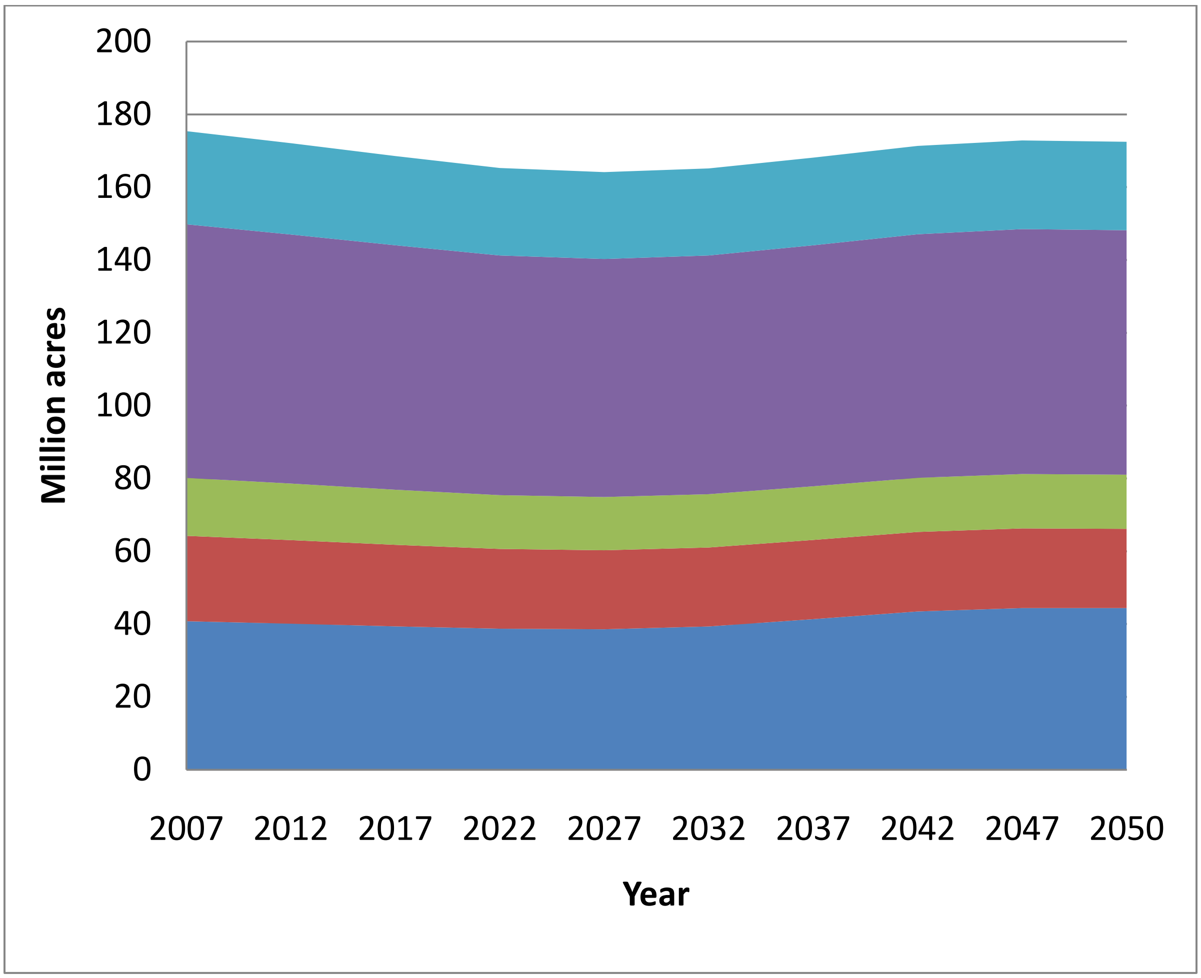
(B)



350
300
250
200
150
100
50
0
Million green tons
2007
2009
2012
2013
2015
2017
2019
2021
2023
2025
2027
2029
2031
2033
2035
2037
2039
2041
2043
2045
2047
2049
Year
Hardwood displacement
Softwood displacement
Hardwood new removal
Softwood new removal
Hardwood harvest residue
Softwood harvest residue

Figure 10-25—Under a low-productivity strategy, Private forest acreage change in the South, assuming (A) moderate and (B) high consumption of woody biomass for energy.

(A)



(B)

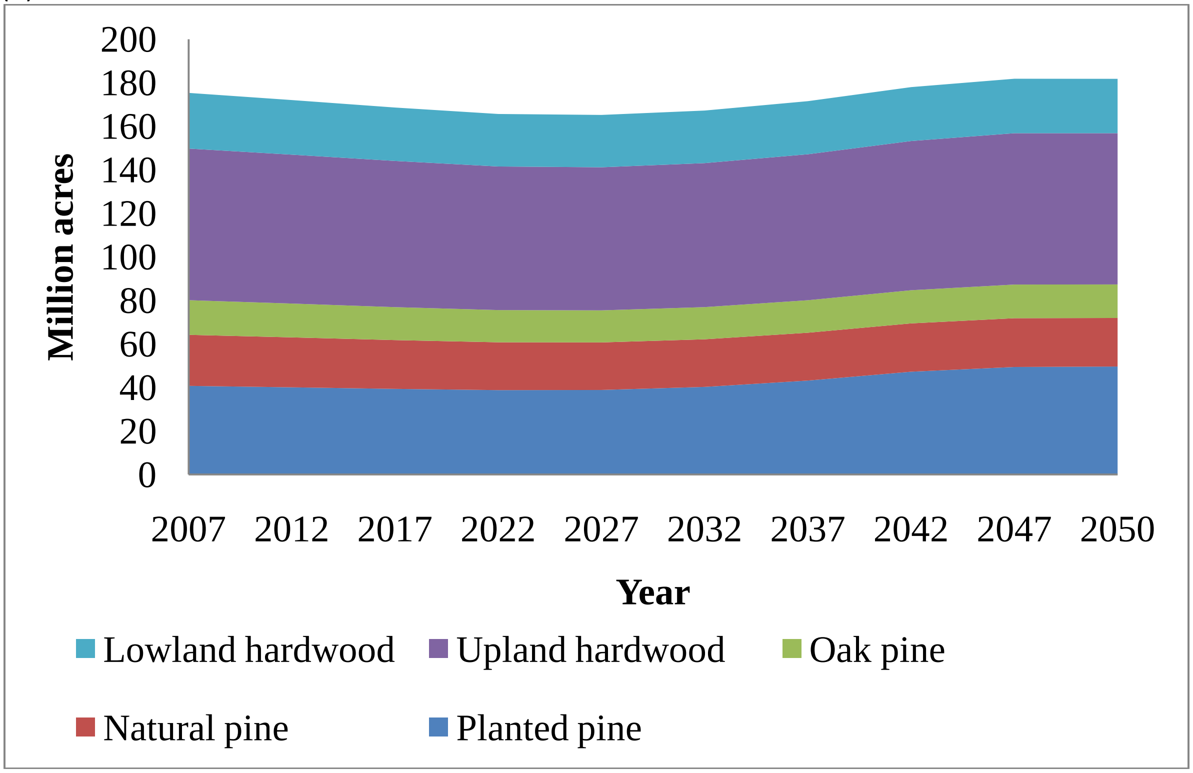
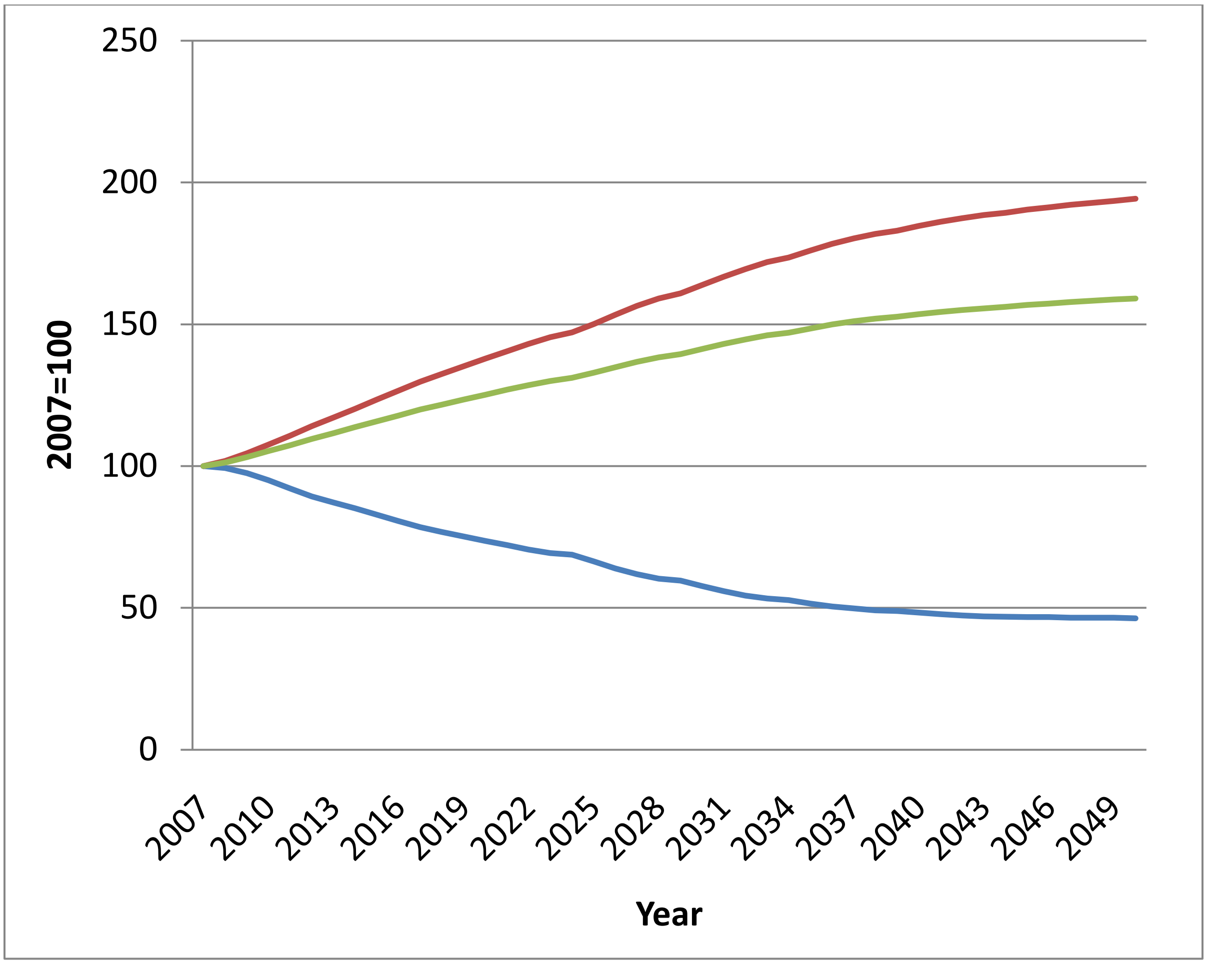
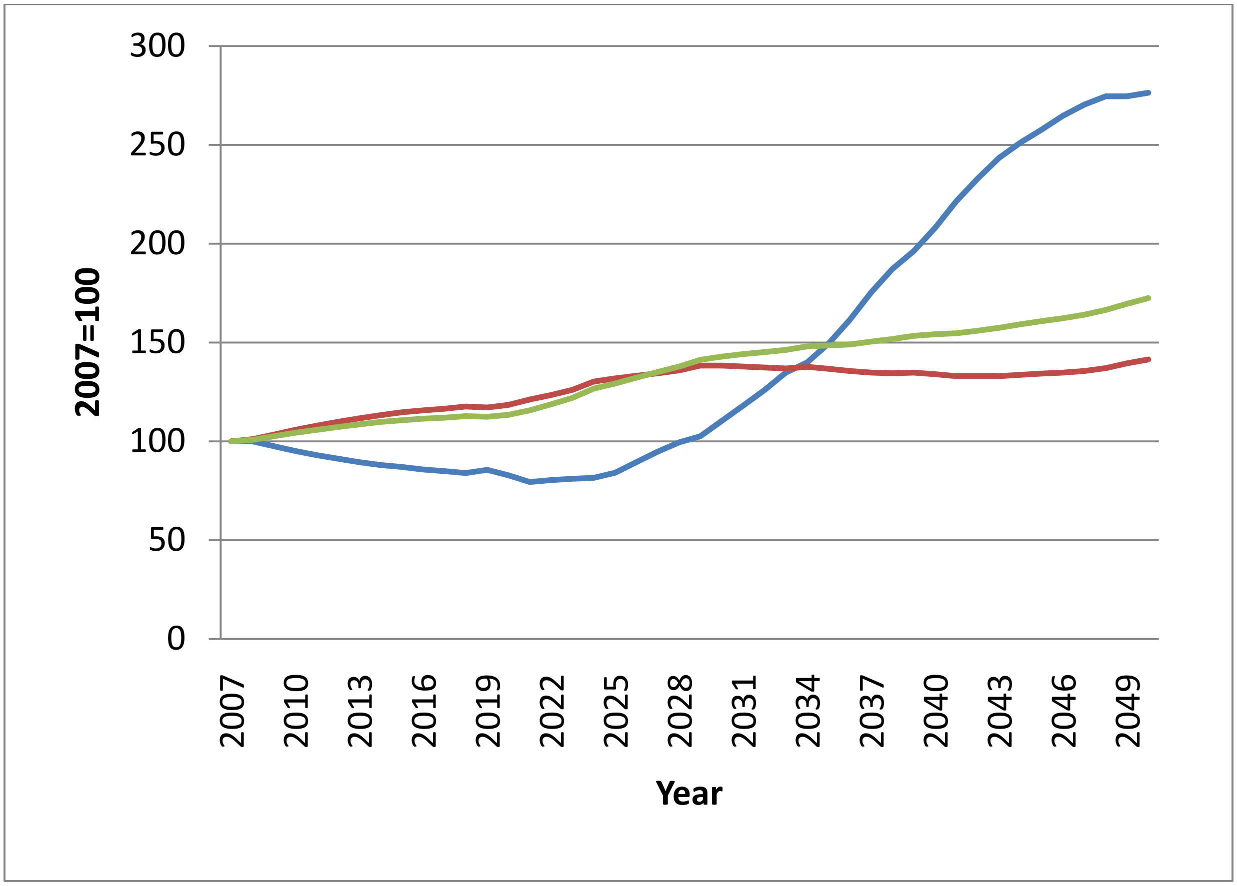

200
180
160
140
120
100
80
60
40
20
0
Million acres
2007 2012 2017 2022 2027 2032 2037 2042 2047 2050
Year
Lowland hardwood
Upland hardwood
Oak pine
Natural pine
Planted pine

Figure 10-26—Under a high productivity strategy that expands short rotation woody crops, market responses in price, inventory, and removals for southern (A) softwood sawtimber, (B) other softwoods, (C) hardwood sawtimber, and (D) other hardwoods.

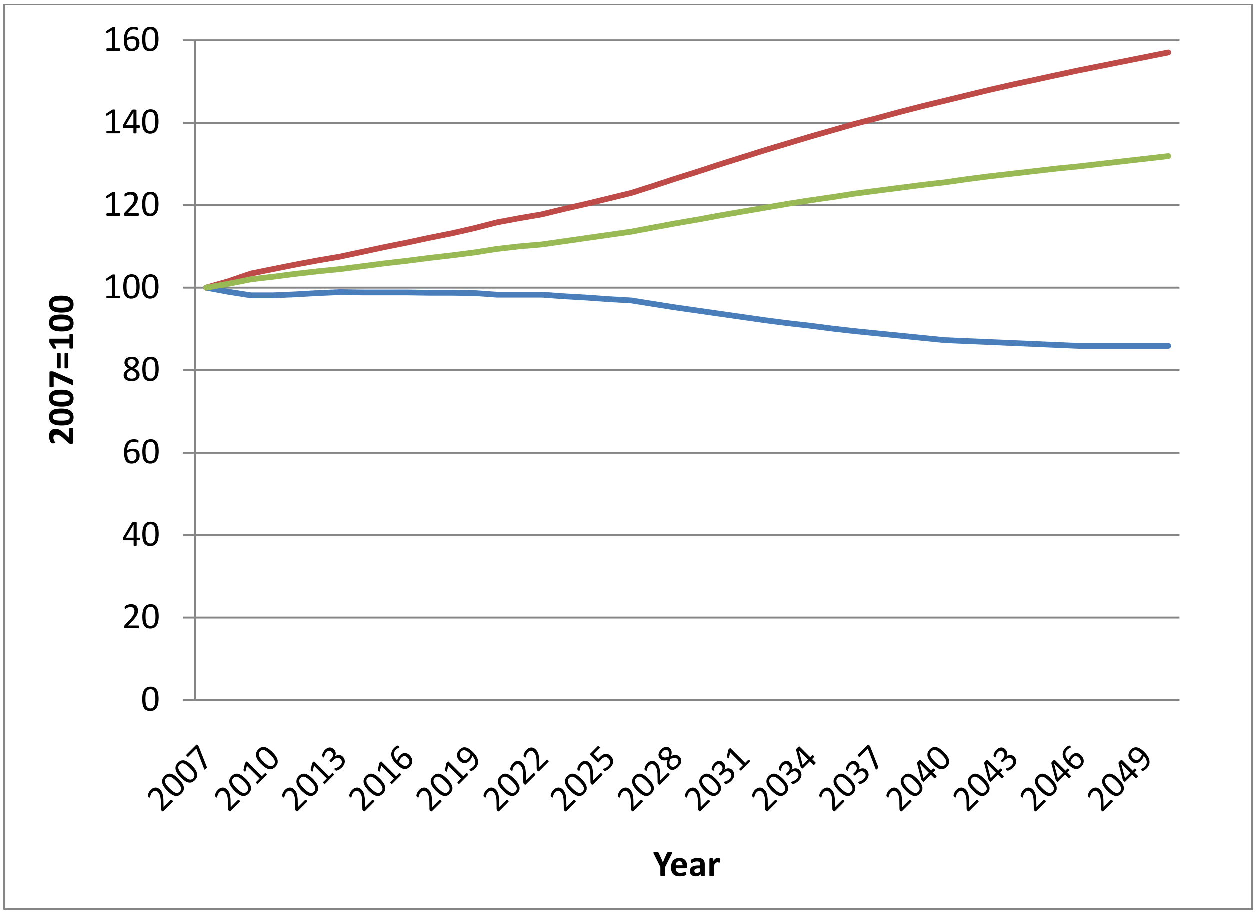
(A)



(B)


300
250
200
150
100
50
0
2007=100
2007
2010
2013
2016
2019
2022
2025
2028
2031
2034
2037
2040
2043
2046
2049
Year

(C)



160
140
120
100
80
60
40
20
0
2007=100
2007
2010
2013
2016
2019
2022
2025
2028
2031
2034
2037
2040
2043
2046
2049
Year

(D)

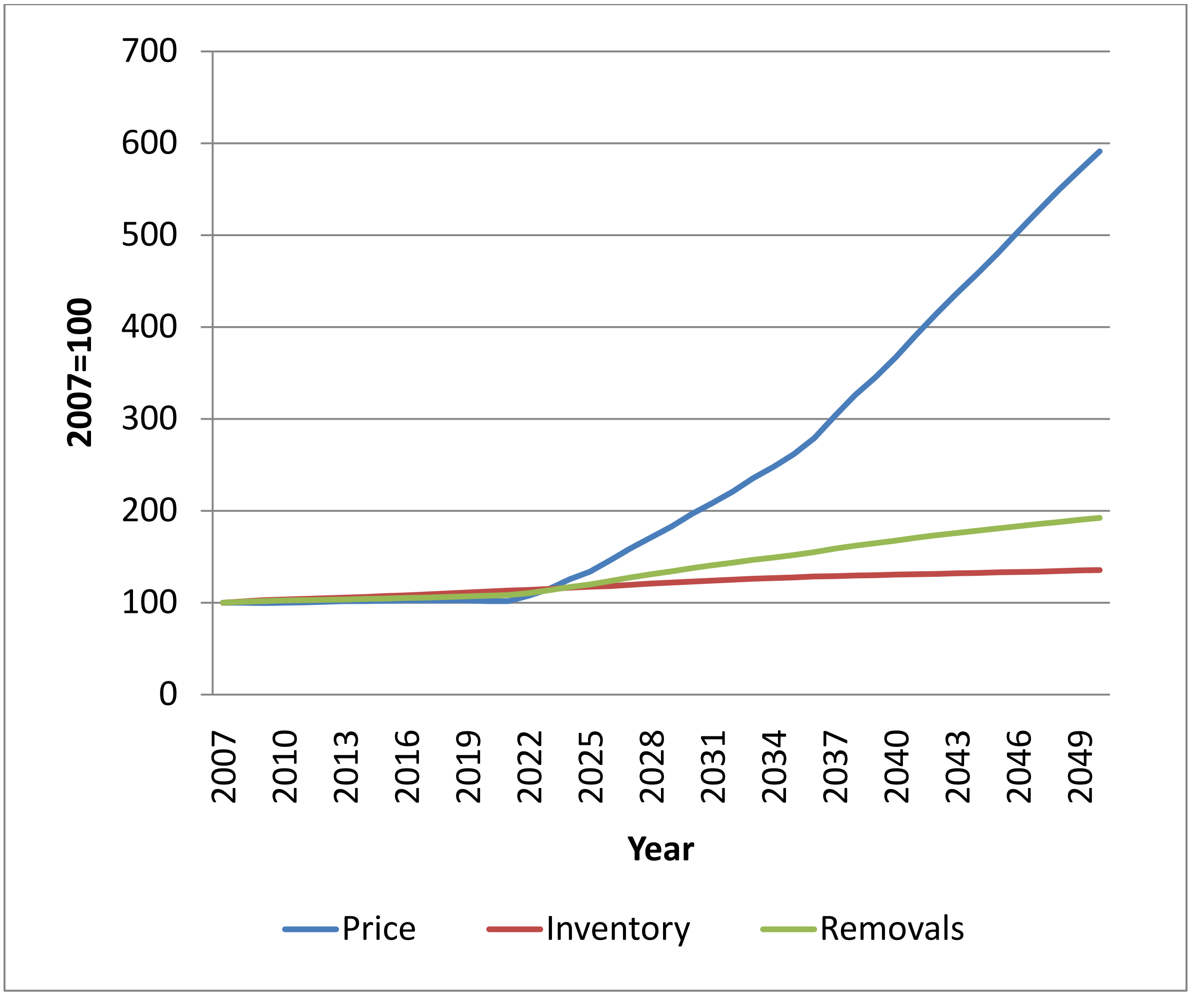

700
600
500
400
300
200
100
0
2007=100
2007
2010
2013
2016
2019
2022
2025
2028
2031
2034
2037
2040
2043
2046
2049
Year
Price
Inventory
Removals

Figure 10-27—Under a high productivity strategy that expands short rotation woody crops, feedstock composition in the South, assuming high consumption of woody biomass for energy.

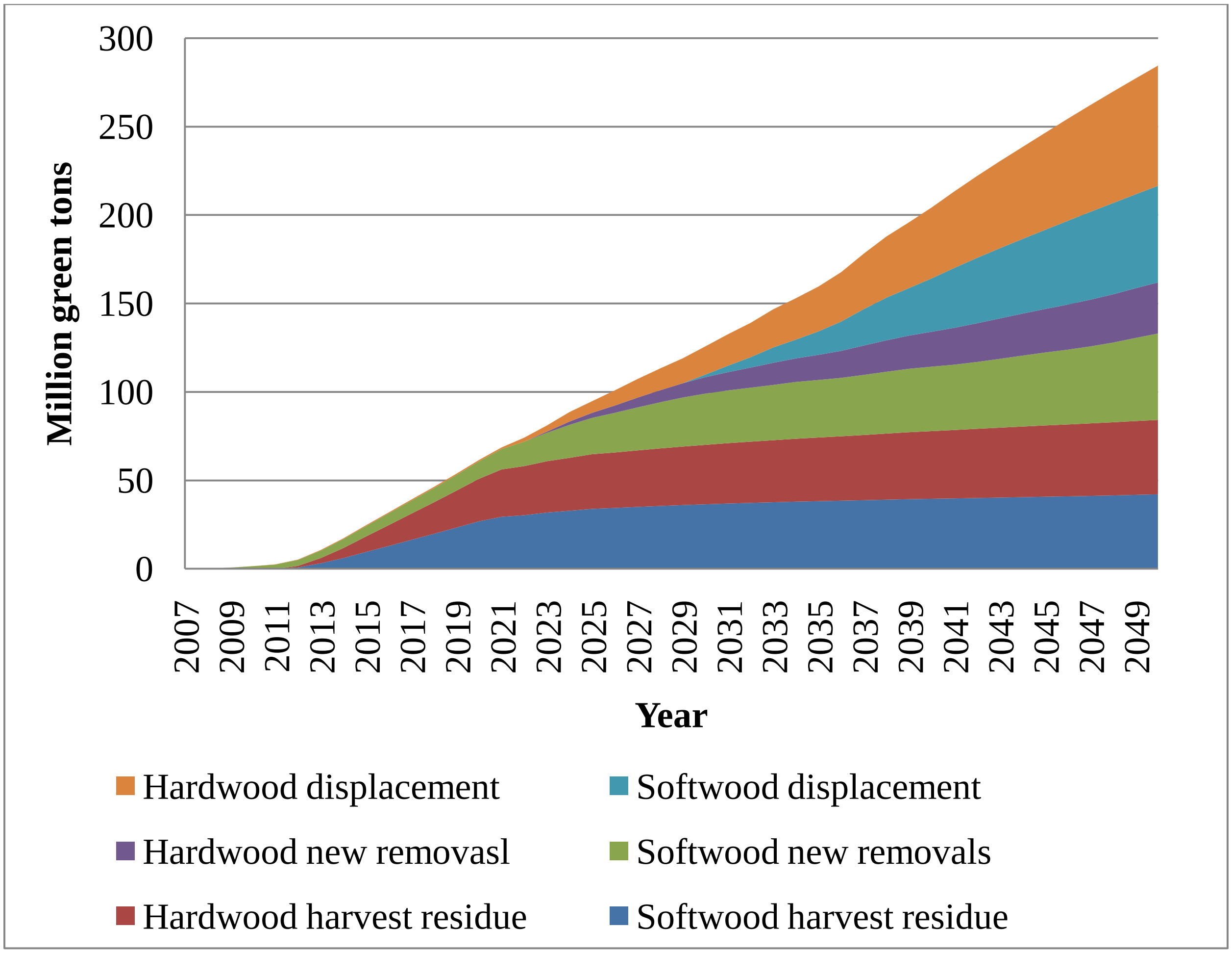


Figure 10-28—Under a high productivity strategy that expands short rotation woody crops, private forest acreage change in the South, assuming high consumption of woody biomass for energy.

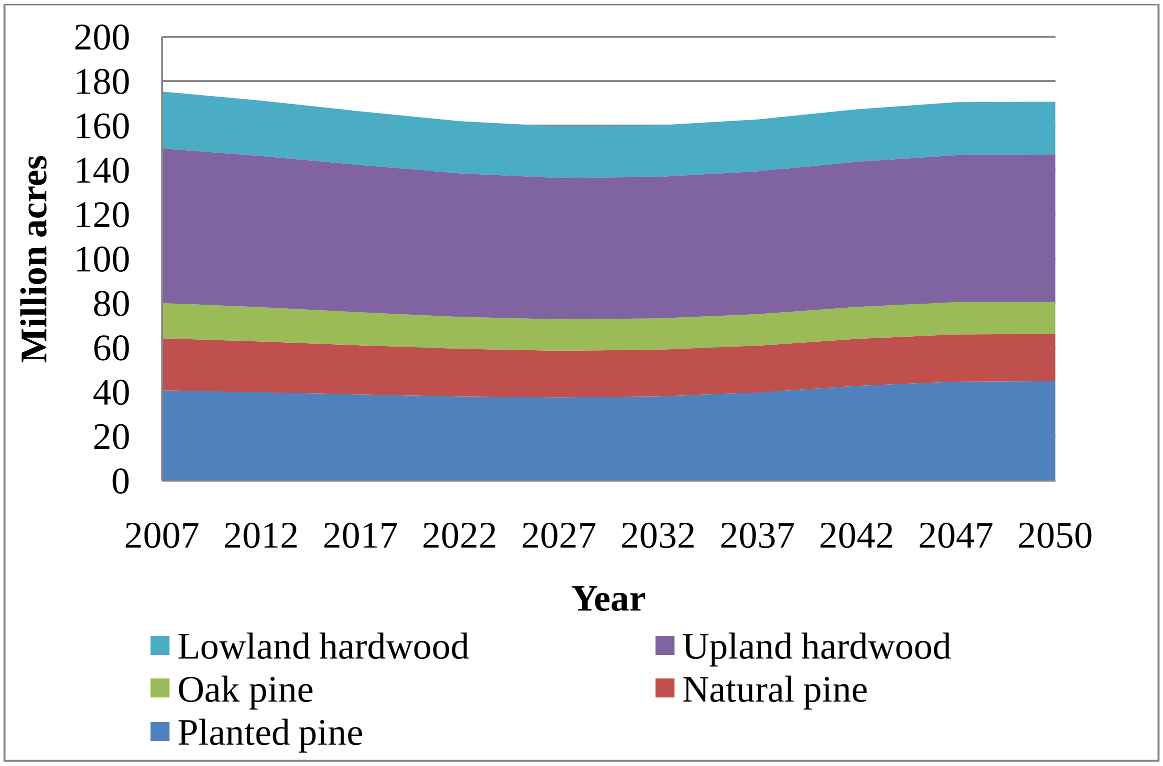


Figure 10-29—Co-firing plants, location and megawatt capacity, in the South, 2007 (source: Energy Information Administration, available at http://www.eia.doe.gov/cneaf/solar.renewables/page/trends/table1_9.pdf).

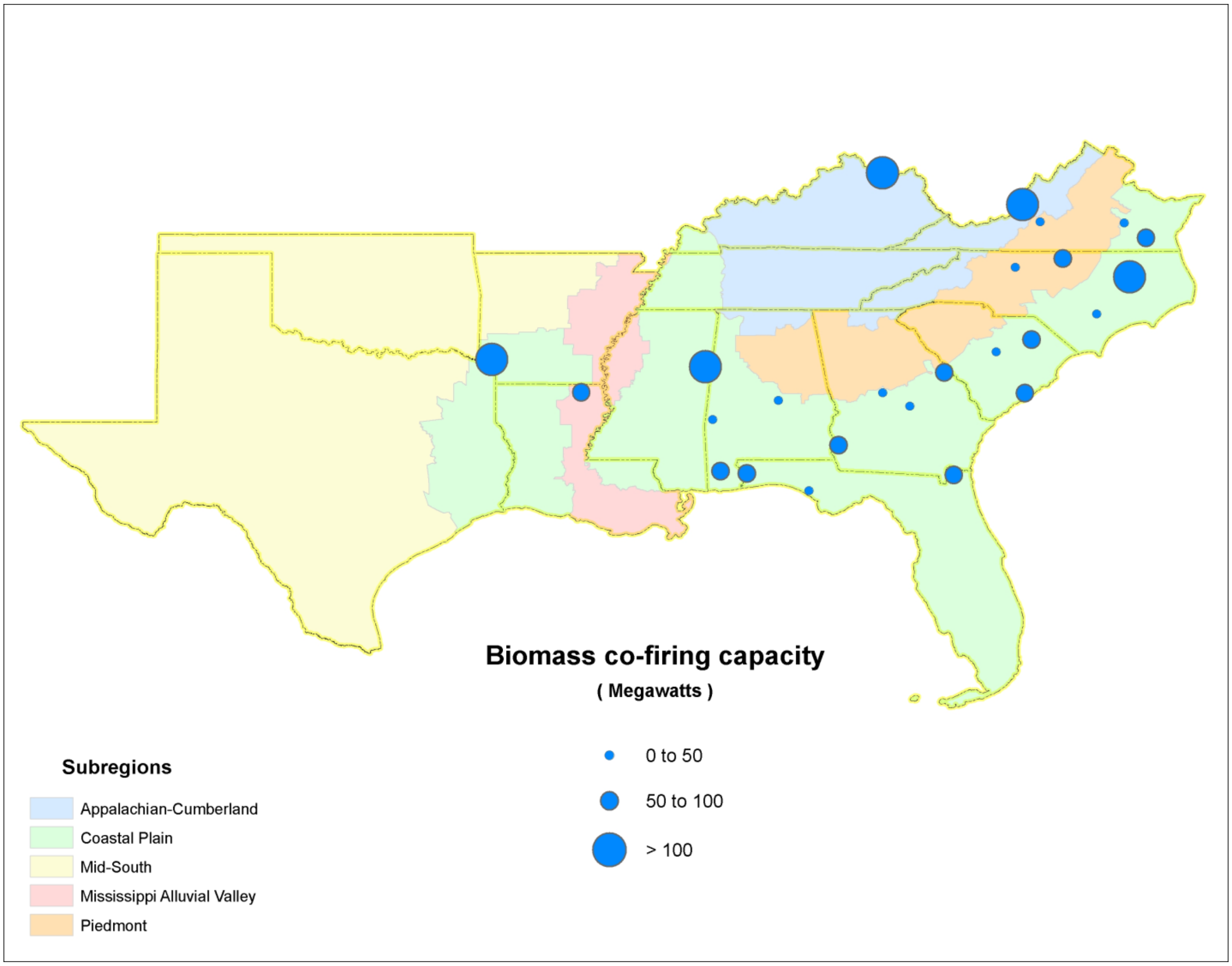


Figure 10-30—Combined heat and power plants, location and capacity, in the South, 2009 (source: Energy Information Administration, 2010c).

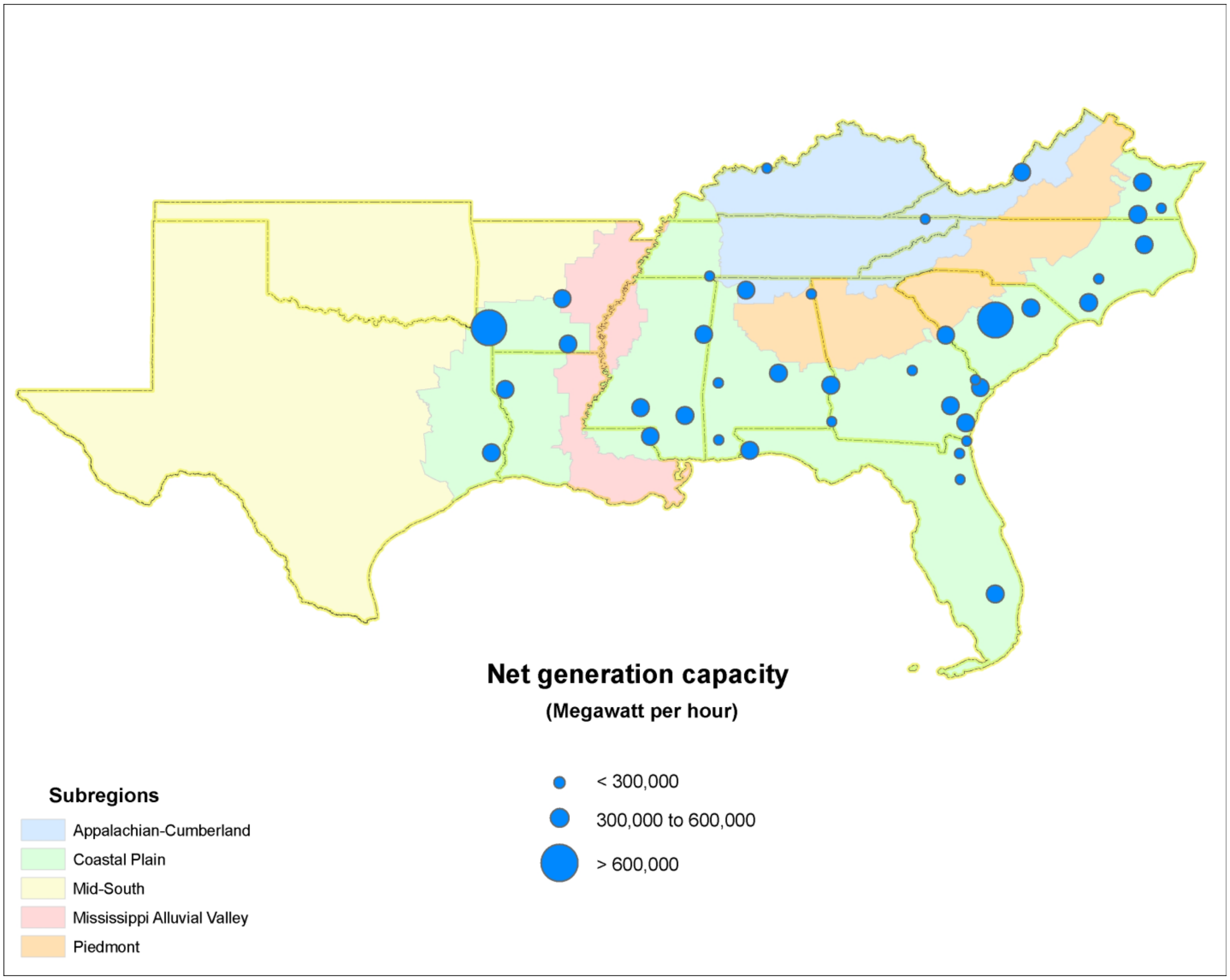


Figure 10-31—Wood pellet mills and locations in the South (source: Pellets Fuels Institute, 2010).

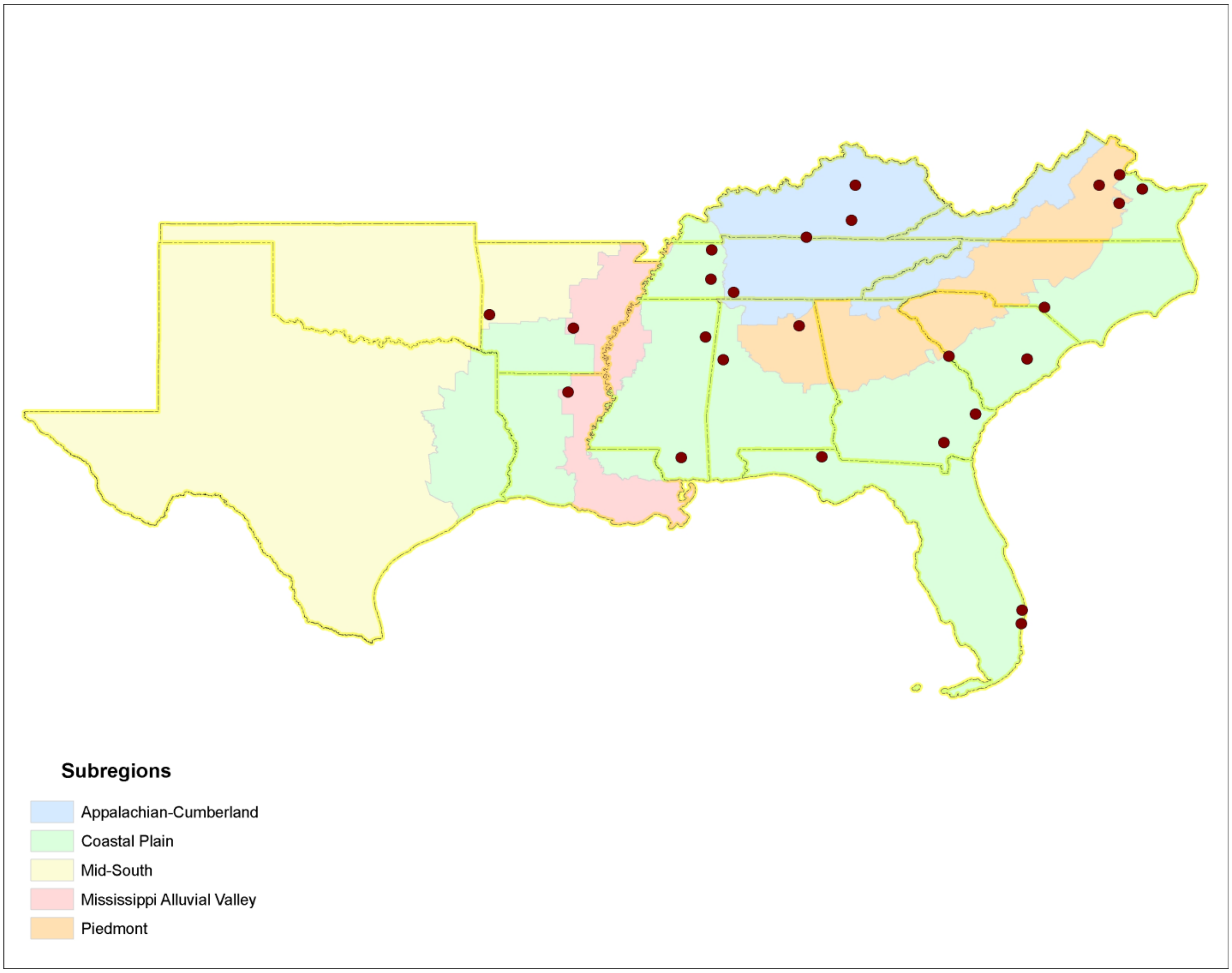


Figure 10-32—Producers of ethanol in the South, with locations and capacity (sources: Renewable Fuels Association, available at http://www.ethanolrfa.org/industry/locations/; accessed January 7, 2010).