

# Effect of Bioenergy Demands and Supply Response on Markets, Carbon, and Land Use

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**Abstract:** An increase in the demand for wood for energy, including liquid fuels, bioelectricity, and pellets, has the potential to affect traditional wood users, forestland uses, management intensities, and, ultimately, carbon sequestration. Recent studies have shown that increases in bioenergy harvests could lead to displacement of traditional wood-using industries in the short run and intensive management, land use change, and sawtimber market impacts in the long-run. We simulate timber markets, as well as land use response and carbon outcomes resulting from projections of both traditional and bioenergy wood use in Alabama, Georgia, and Florida under differing levels of market supply responses. Increased logging residue recovery had a moderating effect on prices, although increased planting response led to higher carbon sequestration, and smaller effects on prices. Increased forest productivity led to lower prices, but also led to reduced timberland and thus lower forest carbon sequestration. Supply responses will be crucial to moderating market responses to increases in bioenergy wood demands. *FOR. SCI.* 58(5):523–539.

**Keywords:** woody biomass, timber supply, timber demand, logging residue, carbon sequestration

THE POTENTIAL FOR INCREASED USE OF WOOD in producing energy has added uncertainty to forest management and timber markets. Although the demand for wood for bioenergy is primarily policy-driven at this time, changes in the prices of fossil fuels could make the use of wood for energy a viable market alternative in the production of liquid fuels or electricity. Regardless of the impetus, however, increasing demands for wood will influence both the existing demand from traditional wood users as well as the potential supply responses. In this analysis, we use a market model of supply and demand, combined with biomass demands developed by Forisk Consulting (Brooks Mendell, pers. comm., Jan. 17, 2011) to address potential market responses. We evaluate how markets, land use, and on-site forest carbon are affected by supply responses. The potential supply responses we evaluate are logging residue recovery rates, increased pine plantation growth, and increased planting response to stumpage prices.

Typical approaches to evaluating the wood bioenergy markets include the following: assessments of potential available woody biomass (Perlack et al. 2005, Gan and Smith 2006, Biomass Research and Development Board [BRDI] 2008, Perez-Verdin et al. 2009) that do not include models of biomass demand; market models of both supply and demand, using policy-based biomass demands (Galik et al. 2009, Rossi et al. 2010, Abt et al. 2010a, 2010b, Ince et al. 2011); and facility location evaluations, often including optimal plant size in addition to plant locations (Wu et al. 2011). Carbon impacts of this changing market have also been assessed, focusing on national (Gan and Smith 2006) or regional implications (Abt et al. 2010b), or assessing the

changes in carbon resulting from biological changes without including potential market responses (Manomet Center for Conservation Sciences 2010, Biomass Energy Resource Center 2012).

The current low level of logging residue recovery (LRR) will probably increase to supply the bioenergy market. The level of LRR is addressed in most analyses of woody bioenergy demand, in part because residues are specified in some federal and state policies as the only type of woody biomass that qualifies as renewable (Bracmort and Gorte 2009). Depending on the temporal scale chosen, carbon accounting of forest residues is also a fairly straightforward exercise. Recent studies suggest that the use of LRR for bioenergy may lead to a net increase in carbon emissions in the near term, but that the emission differential falls over time (Repo et al. 2011, Domke et al. 2012). Other studies (e.g., Abt et al. 2010b) assume that the long-term differential is negligible, implicitly treating the pool as carbon neutral.

Existing forest landowners probably will also increase their investments in intensive pine plantation management if prices increase. A recent summary by Munsell and Fox (2010) provides support for the potential benefits resulting from increased management of pine plantations. The various treatments, including tree improvement, genetics, tillage, fertilizer, and competition control, are shown to be economically beneficial to forest landowners (Allen et al. 2005), technologically possible (Fox et al. 2007), and sustainable (Fox 2000).

Land in timber production has been shown to increase based on relative changes in agriculture and forest rents

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(Hardie et al. 2000). In this analysis, we use the Hardie et al. (2000) empirical model based on endogenous timber price changes, while holding agriculture rents constant. If timber acreage increases because of timber price increases, we assume that all gains are in pine plantations, although natural forest types remain constant. For this analysis, if timberland is decreasing, losses are distributed proportionally across all broad management types (pine plantation, natural pine, oak-pine, upland hardwoods, and lowland hardwoods).

In the following, we discuss the methods we use to evaluate the potential supply responses to meet varying bioenergy wood demands in a subregion of the Southeastern United States, Alabama, Florida, and Georgia, which is the core of the existing southern forest industry and also has been a focus of the evolving bioenergy industry. We develop demands for both traditional and emerging bioenergy industries. The effects on prices, inventories, and harvest levels, as well as impacts on land use, traditional industries, and carbon sequestration are discussed. The analysis of carbon outcomes is limited to forest carbon inventory within the three states only. It does not include impacts of forests outside these states nor changes in emissions associated with wood products production or substitutes.

## Methods and Data

Below we describe our timber market region, describe the Sub-Regional Timber Supply (SRTS) model used in the simulations, describe the scenario development, and discuss carbon sequestration calculations.

## Timber Market Region: Alabama, Florida, and Georgia

Alabama, Florida, and Georgia have an extensive forest resource base with a concentration of productive pine plantations. More than 33% of the timberland in this region is in privately owned pine plantations (USDA Forest Service 2011). The forest resource currently supports a large forest product industry that consumed more than 90 million metric tons annually from 1989 to 2007 (Figure 1) (USDA Forest Service 2009). The resource base and logging residue availability have also been attractive to the emerging bioenergy industry. Of the announcements of wood-using bioenergy facilities recorded by Forisk Consulting for the southern states, more than 60% of total announced demands in the South were in Alabama, Florida, and Georgia. In the last decade, however, lower prices have led to reduced planting in Georgia and Florida, which will affect future timber supply (Figure 2) (USDA Forest Service 2011). The availability of logging residue is also being affected by the recent drop in wood consumption shown in Figure 1.

Although this region is dominated by pine forests, hardwood forests are also an important component of the forest landscape. In these states, hardwood utilization is dominated by pulpwood, but hardwood pulpwood consumption has been less than 20% of total pulpwood consumption in the last decade (USDA Forest Service 2009). Because hardwoods are not managed intensively in this region, there is no history of management intensification response due to higher prices. Higher prices do tend to keep more land in hardwood forests, and this effect is captured in our analysis.

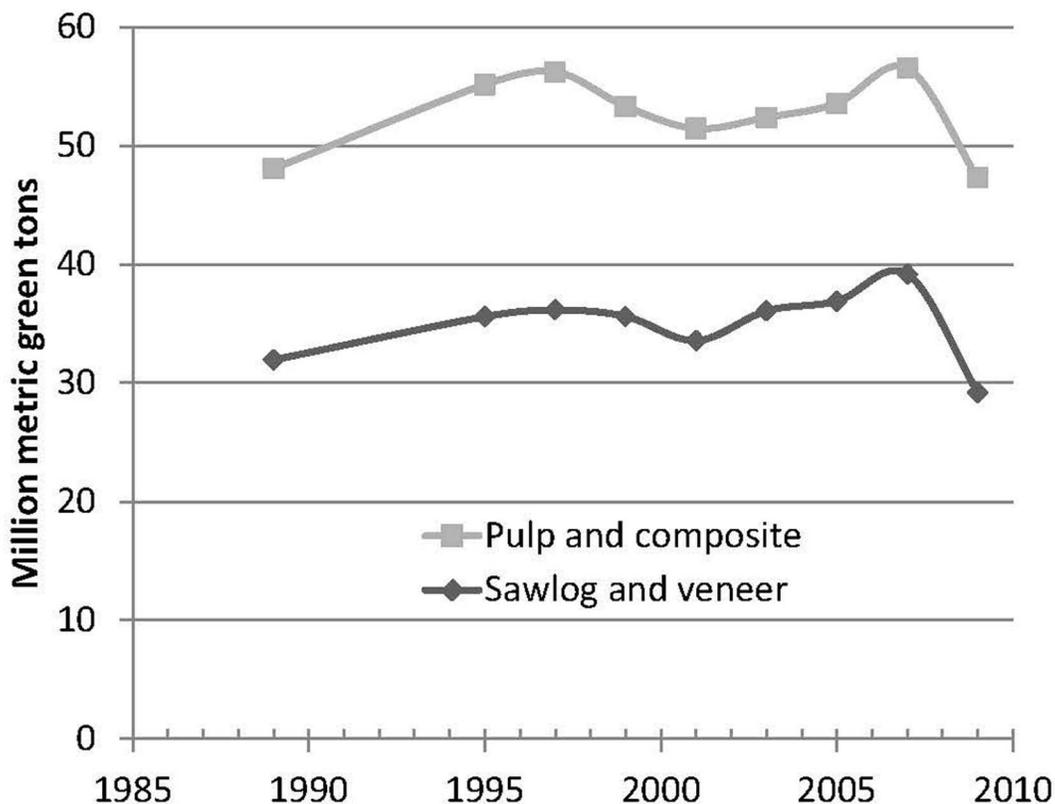


Figure 1. Historical removals for two softwood product groups from 1985 to 2009 for Alabama, Florida, and Georgia (USDA Forest Service 2009).

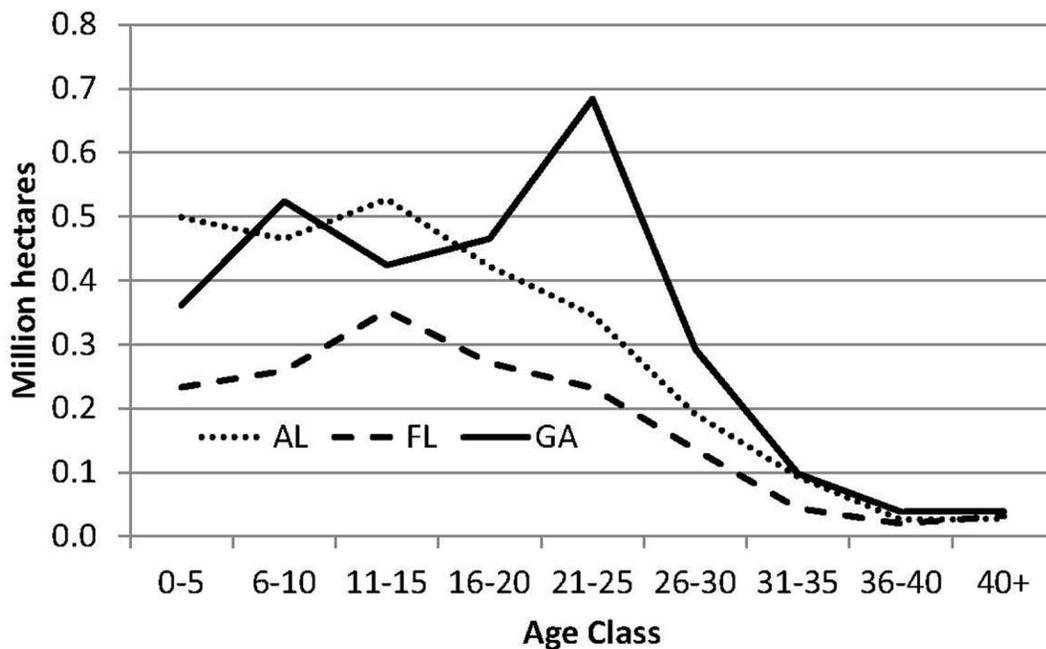


Figure 2. Plantation area by age class from the most recent FIA surveys for Alabama, Florida, and Georgia (USDA Forest Service 2011).

Although hardwood harvests generate more logging residue per unit volume, pine utilization dominates these markets and is the focus of the supply response discussion below.

### Modeling Approach

We used the SRTS model to conduct a partial equilibrium analysis of stumpage markets in the region. The model uses the USDA Forest Service Forest Inventory and Analysis (FIA) (USDA Forest Service 2011) data set of inventory, growth, removals, and acreage by forest type, private ownership category, species group, and age class for multi-county areas (FIA survey units). A supply function with assumed price elasticity of 0.3 and inventory elasticity of 1.0 was equilibrated with a demand function with price elasticity of  $-0.5$ . Previous research by Pattanayak et al. (2002) concluded that there is consensus in the literature that both the supply and demand price response is inelastic (meaning that a large change in price is needed to induce a small change in harvest), although the precise values of these elasticities vary by study.

Once the equilibrium price and quantity of each of the four products were projected for a year, the model used a goal program to determine from which owners and management types the product harvest would come. The goal program reconciles product volumes with observed harvest patterns across forest types and age classes. The harvest was then passed to the biological accounting module, and inventory was updated for the next period's equilibrium calculation. The accounting module tracks inventory by 5-year age classes for the five southern forest types (pine plantations, natural pine, oak-pine, upland hardwoods, and bottomland hardwoods) and for two ownership classes (corporate and other private). Further details of the SRTS model can be found in Abt et al. (2009).

In this analysis, we evaluate four product types: soft-

wood pulpwood, softwood sawtimber, hardwood pulpwood, and hardwood sawtimber. The model grows and harvests trees in response to demands for pulpwood and sawtimber, where the term *pulpwood* is used to describe the growing stock volume in softwood trees of  $<9$  inches dbh or hardwood trees of  $<11$  inches dbh. In addition, a portion of trees in larger diameter classes, which includes top volume and cull, was added to pulpwood volume. Softwood and hardwood volumes in larger diameters, net of this cull proportion, were considered sawtimber. The amount of harvest that was considered logging residue was calculated based on TPO removal proportions (Table 10 in Johnson et al. 2009) by state.

### Scenario Development

#### Traditional Wood Demand

Demand represents the potential consumption of wood at different prices. To develop demand scenarios over time we project consumption of wood in various uses at existing prices. This would represent future consumption only if supply were unconstrained. We then use these demand scenarios to shift the product demand curve in the model. This demand interacts with a supply curve, which is based on current year product inventories and econometrically estimated supply-price relationships. The resulting price and harvest from supply-demand equilibrium is reported as the market outcome. The change in inventory resulting from the harvest and annual growth is also presented.

The projected demand for timber from traditional wood processing for four product types is shown in Figure 3. The 2007–2010 recession can be seen to have had an effect by reducing demand and is followed by a recovery through 2018. We used downscaled national observations of paper and wood products industry value of shipments (US Department of Commerce, Bureau of the Census 2011) to

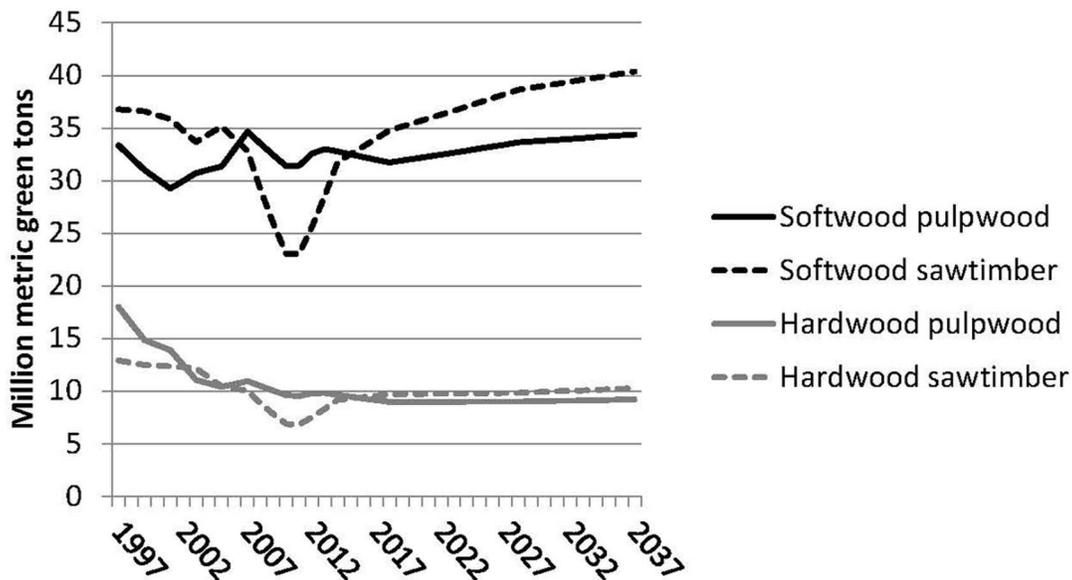


Figure 3. Historical traditional demand for four product groups from 1997 to 2007 and projected traditional demands for 2008 to 2037 for Alabama, Florida, and Georgia.

extend the 2007 timber product output data (USDA Forest Service 2009) to 2010. We then used the Bureau of Labor Statistics 2008–2018 forecast at the national industry level for total industry output (Woods 2009), also downscaled to the state level. Then, assuming a softwood-hardwood mix consistent with state historical trends, we partitioned the changes in industries year-over-year to each of the four products out to 2018. This assumes that the change in value of shipments translates directly to a change in input demand. Beyond 2018, we assume decade-over-decade increases of 10 and 5% for sawtimber and 5 and 2.5% for pulpwood for the second and third decades of the projection, respectively.

Because some policies encourage the use of logging residues and others allow only the use of logging residues, the level of projected traditional wood demand is important in any assessment of the impact of woody bioenergy demand on timber markets. A lower level of timber demand from pulp and paper mills and sawmills, for example, will lead to lower harvest levels and fewer available logging residues. If only residues are allowed to qualify as renewable, then the woody bioenergy industry is explicitly tied to the future of the traditional wood industries. However, if roundwood is used for bioenergy, then the market outcome is more complicated. A lower level of traditional harvest could lead to fewer available residues (which could raise the price of residues and set a physical upper limit on residue supply) but could also lead to higher inventory levels and lower roundwood prices, which would favor increased roundwood utilization for bioenergy.

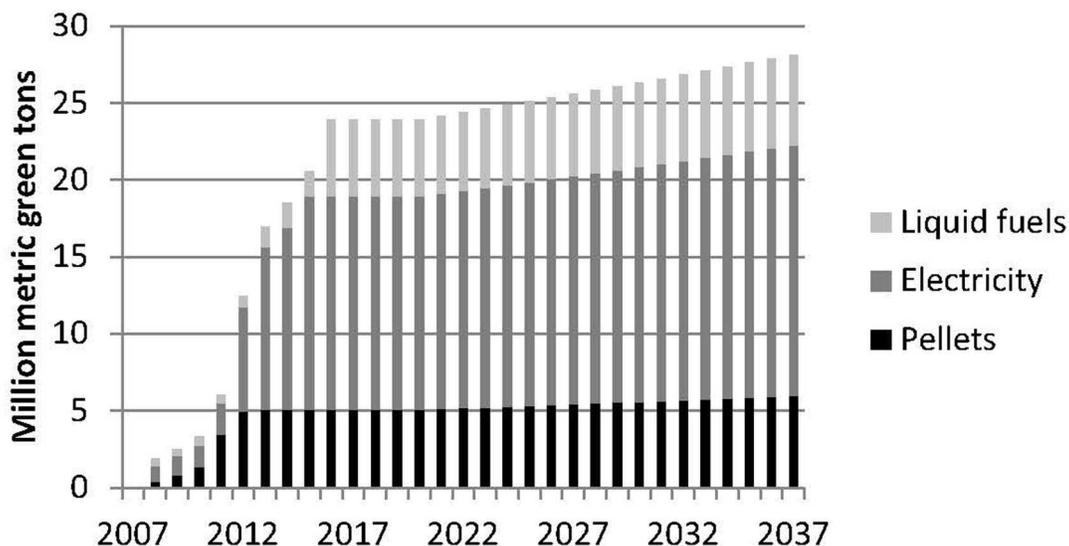
### Bioenergy Wood Demand

Because bioenergy is an emerging industry, econometric relationships have not been estimated for either supplies or demands. The current biomass energy literature focuses on projected consequences of bioenergy policy on bioenergy demands. Examples include Ince et al. (2011), Alavalapati

et al. 2011, the U.S. Billion-Ton Update (US Department of Energy 2011), and US Energy Information Administration policy assessments (US Energy Information Administration 2007). For this analysis, we used a database of announced facilities in the region that would process woody biomass into electricity, wood pellets, and liquid fuels. Forisk Consulting has developed a methodology to project medium-term demand for woody biomass based on an evaluation of viable technologies and the status of the announcements (Forisk Consulting (Brooks Mendell, pers. comm., Jan. 17, 2011)).

Forisk Consulting gathers information on all announced facilities by type and location and then researches the level of commitment made to the facility. These announcements include facilities for the production of liquid fuels, wood pellets, and electricity. Forisk Consulting assesses the announcements for the projected start-up date and includes announcements out to 2020. We use the timber demands from all announced facilities as the bioenergy demand in the region (Figure 4). The start-up dates result in a steep increase in demand in early years and then a leveling off in later years, which will probably be smoothed to a more linear increase as projects are delayed or ended and new projects are announced. A higher level of bioenergy demand could result if the technology for cellulosic ethanol develops and wood-derived fuel is used to meet the Renewable Fuels Standard (US Energy Information Administration 2007) or if the United States adopts a carbon reduction policy or a renewable electricity standard. Conversely, a lower level of bioenergy demand could result if the technology for commercial cellulosic ethanol does not develop, if additional state-level renewable energy standards are not adopted, or if the price of nonrenewable energy falls.

Forisk Consulting provides estimates of actual (2008–2010) and potential (2011–2020) bioenergy demand. We assumed that the level will increase at a rate of 10% per decade for the following two decades of the projection. In



**Figure 4. Bioenergy demand from announced facilities for liquid fuels, pellets, and electricity production for Alabama, Florida, and Georgia from 2007 to 2037 (adapted from Forisk Consulting).**

addition, although Forisk Consulting separates the announcements by end use, they do not estimate how the various uses will use hardwood and softwood species. We use their aggregate woody bioenergy demand value in metric tons (Figure 4) as our bioenergy demand.

We implemented bioenergy demand by calculating available logging residue from existing harvests and assumed that these residues would reduce bioenergy demand for roundwood. The utilization of residues will depend on the mix of bioenergy consumers (e.g., liquid fuels, pellets, and electricity) and the technologies they use. There are also cost, logistics, and logging capacity questions associated with residue supply. To the extent that these factors constrain residue utilization below our assumptions, our estimates of roundwood market impacts are conservative and vice versa.

Residue availability was based on two calculations. The first is an estimate of residue production from harvest operations. The second is LRR over time, which is discussed below under supply responses. For residue production, we used the state-level data recorded in Table 10 in Johnson et al. (2009) to estimate growing stock and nongrowing stock logging residues per ton of growing stock harvest. Table 10 estimates were adjusted to remove stump volumes, which are included in the Forest Service definition of residue but are not usually considered recoverable. Although utilization standards may evolve over time, we held these residue production rates constant over the projection.

Although the above procedure gives us supply estimates of logging residue by size class and species group, our bioenergy demands are not specific to species or size classes. For these projections, we assumed that bioenergy demand would follow the current pulpwood harvest allocation between pine and hardwood. As noted above, this assumes that approximately 80% of bioenergy demand in the region would come from pine.

The procedure for adding bioenergy demand to traditional demand was the following. The Forisk Consulting

database was split into hardwood and pine demand based on current pulpwood harvest. A portion of this demand was met by logging residue based on the availability and the LRR factor for that species group and year. After residue utilization was deducted, the remaining bioenergy demand quantity was used to shift the current year pulpwood demand curve. Because demand and supply are price-inelastic in these markets, demand shifts lead to larger price changes than harvest changes.

The difference between the demand shift and the resulting market equilibrium harvest change for both industries is what we call “displacement.” If we had information on the demand price elasticity of emerging bioenergy demand, it would be possible to simulate the change in the price responsiveness of the combined (existing and bioenergy) industry demand. Because we do not have this information, however, we compare this total displacement quantity to the demand quantities in bioenergy and existing pulpwood consumer. Three potential outcomes could occur.

First, if both industries had the same demand price response, the displacement would be proportional, e.g., demand might be reduced by 20% in each sector because of higher prices. Second, if bioenergy were more price-inelastic (less price-responsive) than traditional industries, the higher market prices would affect the existing wood consumers disproportionately; i.e., a larger than proportionate share of displacement would be due to reduced consumption from the existing industry. Price-inelastic bioenergy demand would be consistent with the view that these demands are policy-driven and that some power markets are regulated so that costs may be passed through to power consumers.

Third, if bioenergy demand were more price-responsive (less price-inelastic) than existing wood consumers, higher wood prices would have a larger impact on bioenergy consumption, and a larger than proportionate share of displacement would be due to reduced consumption by the

bioenergy sector. This view would be consistent with bioenergy firms updating their feedstock price expectations as markets evolve so that fewer announcements become actual facilities. Availability of renewable or carbon-friendly substitute feedstocks at relatively lower prices could also lead to greater bioenergy demand response to wood prices.

For these projections, we assumed that the price elasticity of wood demand did not change with the addition of bioenergy demand, so that the difference between the demand shift due to bioenergy and the resulting harvest is based on a demand price elasticity of  $-0.5$ . In our results we show the proportion of bioenergy or pulpwood demand that this displacement represents. This gives some perspective to how changes in the allocation of displacement would affect the sectors.

### *Supply Response*

Three potential supply responses were evaluated: increased LRR, increased plantation growth, and increased timberland area response. For LRR and growth responses, there are no empirical data to determine market response to demand/price changes. Thus, we make assumptions about the rate of adoption of these responses. For timberland, the model calculates endogenous planting response (Hardie et al. 2000) as described in the introduction, but these responses are sensitive to the definition of forest rent, which we explore below.

We evaluated two end levels of LRR, 33% and 66%, with increases from zero to this level over the first 5 years of the projection. These recovery rates are applied to all harvests, implying that we expect some harvests to be recovered at a higher rate and some at a lower rate to reach this regional average on all harvests. The higher level, 66%, is similar to levels assumed to be the operational maximum level of LRR (Perlack et al. 2005, BRDI 2008) on individual pine stands. We assume that the adjustment process will not be immediate because the logging sector will need to adjust equipment, transportation, and employment capacity to accommodate the new markets.

The initial hectares of pine plantations are derived from the FIA database (USDA Forest Service 2011). Timberland area is projected for each scenario based on Hardie et al. (2000) as a function of pine sawtimber prices. Other inputs are used in Hardie et al. (2000), such as agricultural rents and county population forecasts. Agricultural rents are held constant and the loss of rural land to urbanization is based on the county-level population forecasts used in the Southern Forest Resource Assessment (SFRA) (Prestemon and Abt, 2002). The timber price used in the land use forecast is the previous year's SRTS model output, so that the response of planting in time  $t$  is made in response to the modeled softwood pulpwood and sawtimber prices in time  $t - 1$ . In this analysis, overall timberland change was initially tied primarily to pine sawtimber prices, as developed in the Hardie et al. model. When timberland increases, the increases are assumed to occur in pine plantations, although decreases in timberland are assumed to be proportional across all five management types. To better reflect biomass market impacts on forest rents, we modified the rent calcu-

lation to reflect income from both pulpwood and sawtimber price changes using a net present value calculation. Our calculation takes into account the price and timing differential in these products. This calculation continues to put the primary weight on sawtimber prices, but in times of lower sawtimber prices and high pulpwood prices, a larger proportion of rent is based on pulpwood price.

Current growth rates in the model are developed from regression equations for each management type and physiographic region. These rates represent averages across large areas, and different owners. To model increased growth that is likely to occur on some stands, but not all, due to increases in fertilization, thinning, or genetic selection, we augmented the growth rates on new plantations beginning in 2008, rising to a regionwide average increase of 25% by 2037. Again, assuming a regionwide average of 25% implies that although some individual stands could have growth rates higher than 25% over 30 years, some stands will also have lower growth rates. An earlier study, the SFRA (Prestemon and Abt 2002), used an assumed increase of 50% in growth over 50 years compared with our 25% growth increase over 30 years.

### *Scenarios*

We simulated six scenarios to evaluate the consequences of the three potential supply responses individually or in combination (Table 1). The scenarios include (1) a baseline including only traditional demands, no new bioenergy demands, and no additional supply responses; (2) BIO 1 added bioenergy demand and a supply response of a 33% LRR; (3) BIO 2 doubled the residual supply response by assuming a 66% LRR; (4) BIO 3 added a potential increase in planting response by including pine pulpwood prices in the timber rent calculation; (5) BIO 4 added a 25% increase in growth on new plantations but did not include pulpwood in the rent calculation, and (6) BIO 5 added both the increased planting response of BIO 3 and the increased growth on new plantations of BIO 4.

### *Carbon Sequestration Calculations*

We converted SRTS inventory projections into estimates of on-site forest carbon through the use of FIA-derived ecosystem-level equations (Foley et al. 2009, as based on Smith and Heath 2002 and Smith et al. 2006). These provide carbon estimates for each of the five management types by age class included in the SRTS model. For each year of SRTS output, we calculated the total amount of carbon contained in live tree, dead tree, understory, down deadwood, and forest floor carbon pools across all forested acres in each of the five management types.

Note that this analysis accounts only for changes in forest carbon and is not a complete carbon accounting of the greenhouse gas (GHG) effects, which would require a assessment of fossil fuel substitution and a life cycle analysis of bioenergy GHG emissions (see, e.g., Mann and Spath 2001). We also take a simplified approach to LRR carbon accounting, assuming a negligible difference between near-term use of residues for bioenergy and their long-term

**Table 1. Definition of baseline and bioenergy demand scenarios with varying supply responses.**

Scenario	Supply response		
	Residue recovery	Increased planting response	Growth increase
Baseline: traditional demand only (no bioenergy demand or supply response)	NA	Timber rent based on pine sawtimber prices	None
BIO 1: traditional + bioenergy demand; 33% LRR	33%	Timber rent based on pine sawtimber prices	None
BIO 2: traditional + bioenergy demand; 66% LRR	66%	Timber rent based on pine sawtimber prices	None
BIO 3: traditional + bioenergy demand; 66% LRR; increased planting response	66%	Timber rent based on pine pulpwood and sawtimber prices	None
BIO 4: traditional + bioenergy demand; 66% LRR; 25% growth increase	66%	Timber rent based on pine sawtimber prices	25% on new planting by end of projection
BIO 5: traditional + bioenergy demand; 66% LRR; increased planting response; 25% growth increase	66%	Timber rent based on pine pulpwood and sawtimber prices	25% on new planting by end of projection

NA, not applicable; LRR, logging residue recovery.

decomposition on the ground. We therefore exclude carbon stored in harvest residues from our estimates of forest carbon, because the pool is effectively canceled out by including it in both the bioenergy and baseline scenarios. Other research has explored the effect of displaced fossil emissions on net GHG balance (e.g., Abt et al. 2010b); therefore, this analysis is limited to the carbon implications of shifts in timberland and inventory only. Finally, we evaluate only the three states listed above, and do not include impacts on forests outside these states, nor do we include any changes in emissions associated with the production of wood products or their substitutes. Our analysis focuses on the net forest carbon impacts of increased demand for bioenergy and a set of expected supply responses to this demand.

## Results and Discussion

The results are presented in Figures 5–12. Figure 5 shows softwood pulpwood market responses from 2007 to 2037, and Figure 6 shows softwood sawtimber responses for that same period. There are few impacts on the hardwood market, both because of the initial effect of changes in demand, based on the proportion of the market fulfilled by hardwoods, and because the hardwood forest types are not typically intensively managed to improve growth nor are they planted. Plantation acres over time are shown in Figure 7 for all six scenarios, and Figure 8 shows the land use changes by planted and natural forest types over the projection by scenario. Figure 9 shows the bioenergy feedstocks from forests including residue use, harvest change, and harvest displacement, and Figure 10 illustrates the range of how total displacement of demand could affect the two industries. Figures 11 and 12 show the three-state forest carbon storage from 2007 to 2037, with Figure 11 showing the total and Figure 12 showing the storage by both natural and planted forest types. Each of the figure and scenario results is discussed in more detail below.

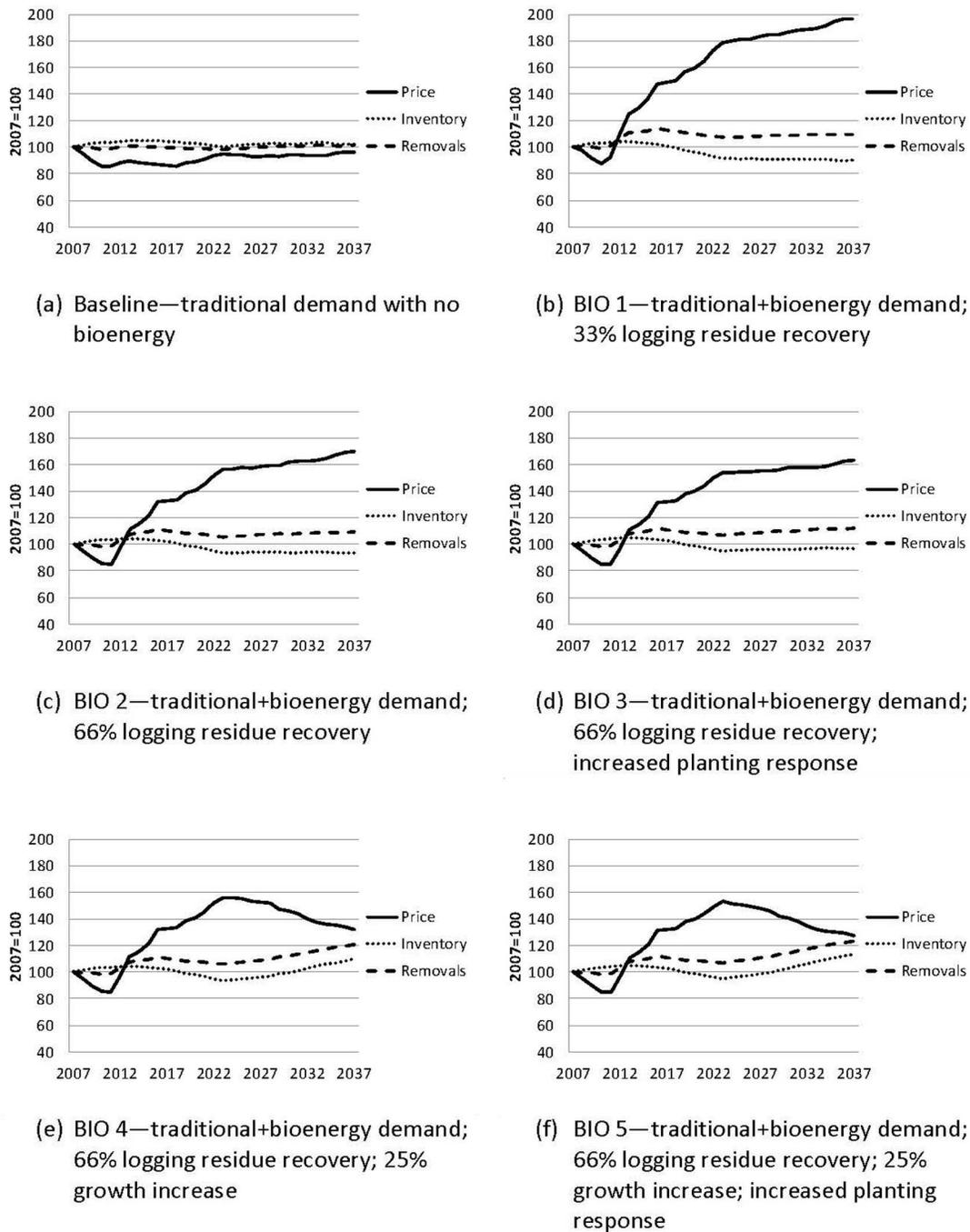
Softwood pulpwood markets respond, as expected, more than the other three product types because any bioenergy demand not met through residue recovery is assumed to be met by using pulpwood. The baseline pulpwood projection

(Figure 5a) shows a decline in price from 2007, with an eventual recovery, although prices never return to the 2007 level. Although acres of young stands are affected by reduced planting, this effect is offset by the “cull” proportion of the growing sawtimber inventory. Removals and inventory stay fairly steady throughout the projection. When bioenergy demand is introduced, but supply response is limited (BIO 1, with only a 33% LRR) (Figure 5b), pulpwood prices rise through the end of the projection, with 2037 97% higher than 2007. Pulpwood inventory rises during the recession, but quickly falls to hover below the 2007 level, and removals show a rise after the recession, but then level off, consistent with our expectations of a market with inelastic price response.

Doubling the logging residual recovery rate to 66% (Figure 5c) reduces the impact on the pulpwood market, with prices rising only by 70% over 2007 levels and smaller effects on both inventory and removals. Adding an enhanced response of planting to pulpwood prices over the 30 year projection moderates the market effects, again leveling off the rising trend so that the projected 2037 value is now only 63% higher than the 2007 value (Figure 5d, BIO 3). Under a supply response of high LRR and an increased growth rate on new plantations (Figure 5e, BIO 4), prices rise as in BIO 2 and BIO 3 through 2023 but then begin to moderate as the new growth on plantations begins to influence the inventory values. Inventory increases, removals increase, and prices fall after 2023, with prices projected at only 32% higher in 2037 than in 2007. Figure 5f shows the combined supply response of 66% LRR plus 25% growth increase plus the increased planting response (BIO 5) and has the lowest price level in 2037 of all of the bioenergy scenarios (at 127% of the 2007 level). An increase in the LRR reduces the overall effect of the bioenergy demands; increased plantation response to pulpwood prices leads to a moderating of price increases and increased growth on plantations leads to a reversal of the rising trend in prices.

Figure 6 shows the response of the softwood sawtimber market to the six supply response scenarios.

Pulpwood and sawtimber are linked in the model through product definitions because a percentage of the sawtimber

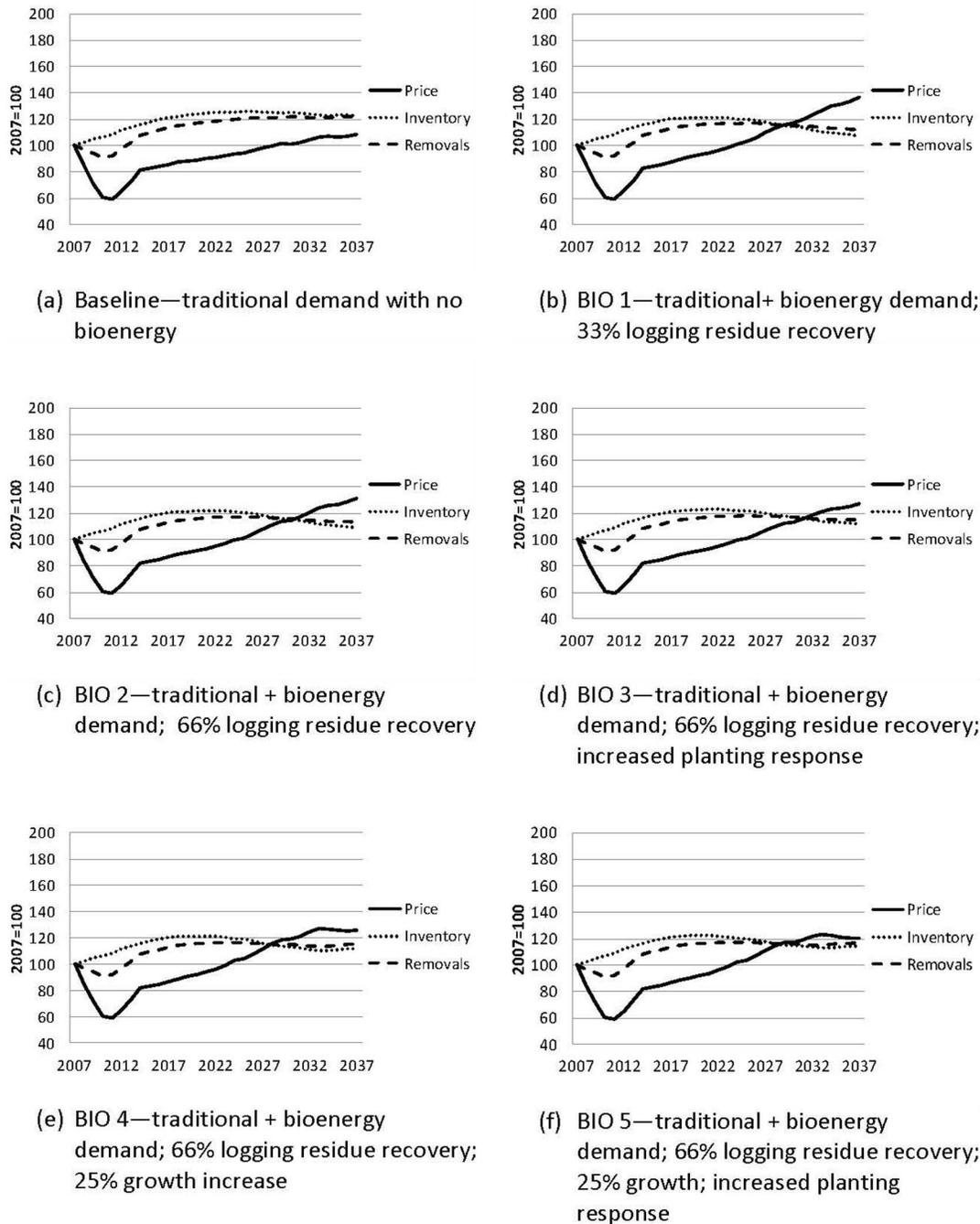


**Figure 5.** Softwood pulpwood: comparison of prices, inventory, and removals from simulations of the baseline and five bioenergy supply response scenarios for Alabama, Florida, and Georgia from 2007 to 2037.

size class is classified as pulpwood, and increased harvest of pulpwood reduces ingrowth into the sawtimber category [1]. Sawtimber harvests are a key component of logging residue production. Because sawtimber prices are currently at about three times the level of pulpwood prices [2], we do not expect that sawtimber will be used to provide bioenergy over the projection period. Even in the lowest supply response scenario (BIO 1), pulpwood prices rise only to about double their current level, not high enough to induce the use of sawtimber for pulpwood or biomass except at the margin.

The baseline (Figure 6a) shows a large and long-lasting

effect of the recession on softwood sawtimber markets, with a return of prices to 2007 levels not projected until 2027. This is a result of only our traditional demand projection and the buildup in sawtimber inventories, because bioenergy demand is not included in the baseline projections. Inventory levels rise sufficiently in the early years to allow removals to recover with slower recovery in price levels. In the scenario with the largest harvesting impact (BIO 1, the smallest supply response of the five we examined), prices rise more rapidly, returning to 2007 levels 4 years earlier and continuing at a higher rate of increase through the end



**Figure 6. Softwood sawtimber: comparison of prices, inventory, and removals from simulations of the baseline and five bioenergy supply response scenarios for Alabama, Florida, and Georgia from 2007 to 2037.**

of the projection (Figure 6b, BIO 1). Correspondingly, the levels of removals and inventory begin to decline somewhat toward the last decade of the projection.

Doubling the residue recovery rate has effects similar to the effects on the pulpwood market, although not as dramatic because as noted above this market is assumed to not be directly affected by the changes in roundwood demand caused by the changes in residue recovery rates (Figure 6c, BIO 2). The year in which price returns to the 2007 level is delayed by more than a year, and the ending price increase is only 31% compared with 36% in BIO 1. Addition of the increased response of planting to pulpwood prices further moderates the increase (Figure 6d, BIO 3) to 27% above

2007 levels. The addition of a 25% growth increase, shown in Figure 6e (BIO 4), instead of the change in planting response, results in very similar outcomes, and combining both growth and planting responses leads to the least increase in prices over the projection, similar to the response of the pulpwood market discussed above (Figure 6f, BIO 5).

Although not displayed in detailed figures, the scenarios included projections for the hardwood pulpwood and hardwood sawtimber markets. Overall, these markets were little affected by most of the scenarios, in part because hardwoods comprise a smaller portion of the overall timber markets in these three states but largely because the supply

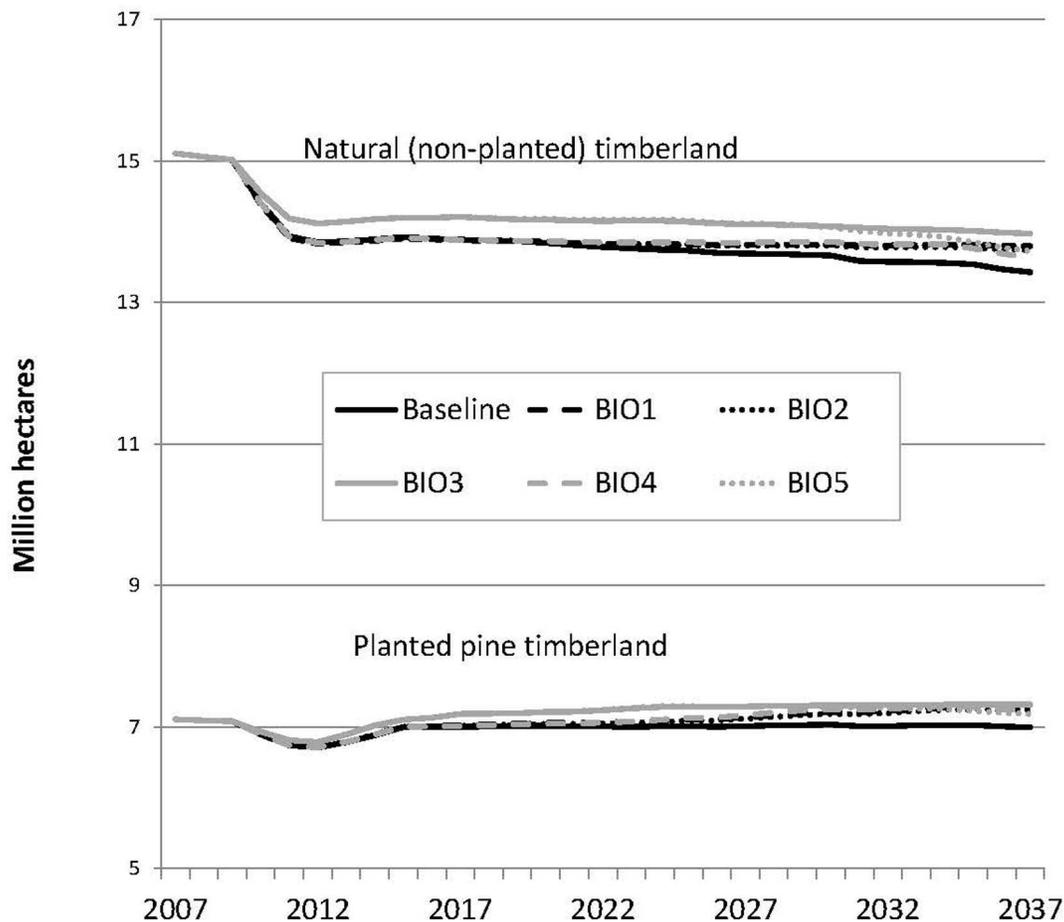


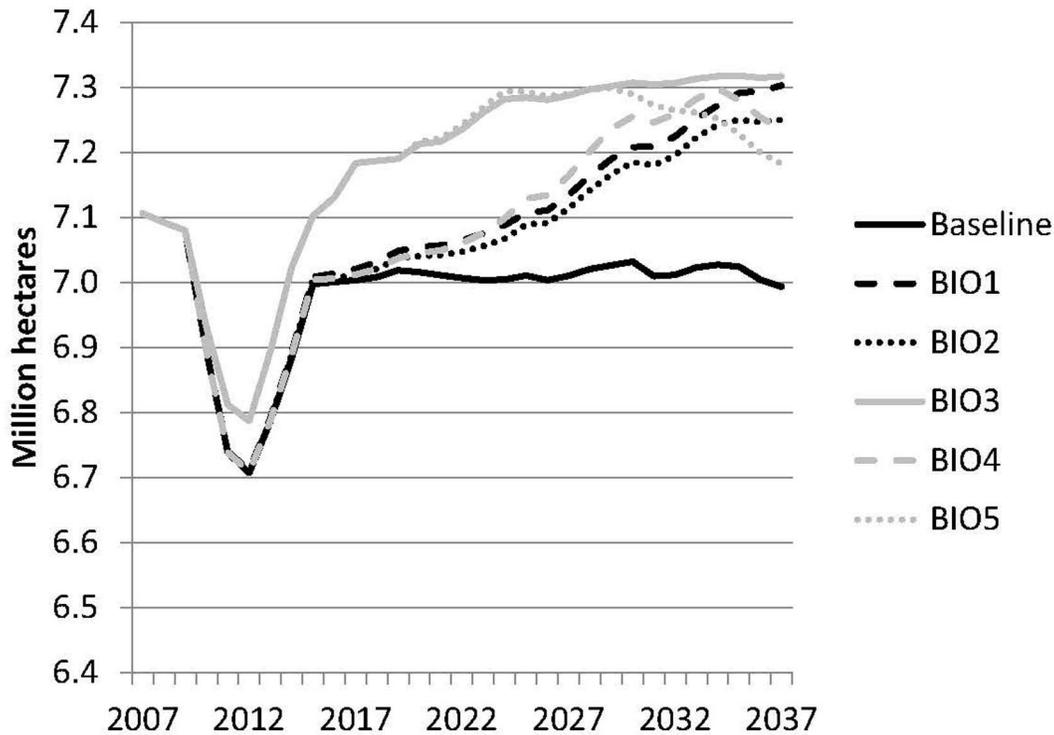
Figure 7. Area of planted and natural timberland from simulations of the baseline and five bioenergy supply response scenarios for Alabama, Florida, and Georgia from 2007 to 2037.

responses of growth increase and planting response do not affect hardwoods. Only the change in LRR had noticeable effects on the hardwood simulations.

The baseline projections for hardwood pulpwood show a continuation of the rises in hardwood inventory and corresponding declines in prices. Removals recover from the recession in 2023. Adding bioenergy demands and the 33% LRR leads to a spike in price as demands increase, but then price smooths out, ending at 30% over 2007 levels, although both inventory and removals are also above 2007 levels because of increased growth in the hardwood inventory. The doubling of LRR to 66% removes the large price increase, with prices recovering only to 90% of the 2007 levels. None of the other supply responses change the hardwood pulpwood projections noticeably. For hardwood sawtimber, the baseline reflects the recession and recovery, with prices slightly below 2007 levels, but inventory and removals slightly higher. The addition of bioenergy demand keeps prices slightly higher, but there are few other changes over the supply response scenarios. Because hardwoods are not expected to have increased growth or to be planted in substantial numbers, these results are expected.

Overall changes in both pine plantation and natural timberland area for the three states over the projection period for the six scenarios are shown in Figure 7. Although the differences are small relative to overall timberland area,

Figure 8 provides more detail on the changes in pine plantations. After the recession, the baseline plantation area returns to a stable level approximately 0.1 million ha below the 2007 value of 7.1 million ha. This is partially due to an assumption that plantation gains occur at the extensive margin, but it is primarily due to low pine sawtimber prices for much of the projection period. All of the bioenergy scenarios lead to higher planting, resulting from the increases in pulpwood and/or sawtimber prices as a result of the new bioenergy demands. The variation results from the differing supply responses and their effects on pulpwood and sawtimber prices. Increasing the planting responsiveness to pulpwood prices leads to higher projected land area in plantations (BIO 3 and BIO 5), with the addition of growth tempering the increase in area as a result of the lower softwood product prices. Total timberland acres decreased 8% in the baseline and 5–6% in the bioenergy scenarios. These results have less plantation area increases than prior regional assessments including the SFRA (Prestemon and Abt 2002) and more recently the Southern Forest Futures Project (Huggett et al. 2011). SFRA was conducted when the relevant policy questions were related to how the southern resource would respond to anticipated higher demands for wood products. Those studies suggested an expansion of the plantation base consistent with current plantation acreage. The Southern Forest Futures Project is based



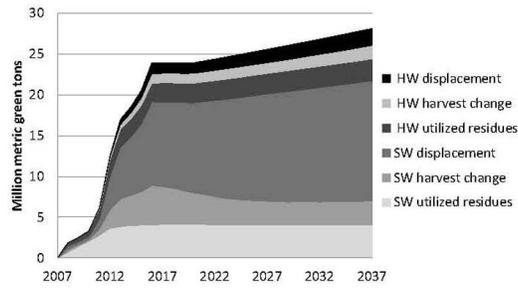
**Figure 8.** Detailed area of planted pine timberland from simulations of the baseline and five bioenergy supply response scenarios for Alabama, Florida, and Georgia from 2007 to 2037.

on demand scenarios derived from Intergovernmental Panel on Climate Change global change scenarios and uses transition matrices and planting rates consistent with price scenarios embedded in a set of cornerstone solutions. Each of these scenarios project higher acreage of plantations than we do, but the study does not include the current recession, which dominates the short-term outlook in this study.

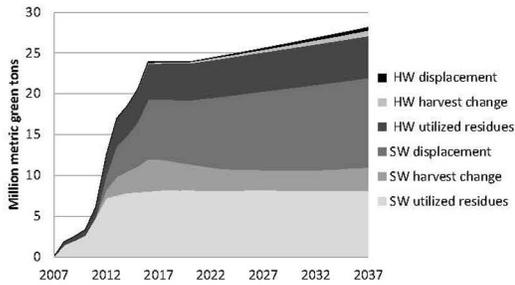
The harvest outcomes and residue recovery assumptions are reflected in the projected bioenergy feedstocks seen in Figure 9, which shows the portion of bioenergy demand met by softwood and hardwood used residues, new harvest, and displacement. As defined above, displacement is the difference between expected demand with no price change and equilibrium harvest that incorporates supply. Only in BIO 1 (Figure 9a), which has the smallest supply response (33% LRR), does hardwood harvest change and displacement play a role; otherwise hardwood residues fulfill most of the demand for hardwoods. In Figure 9b–e, softwood residues show steep increases in the beginning of the projection as LRR rises to 66% in 2012 (BIO 2–5). Actual levels fluctuate in concert with harvest levels. After depletion of available residues, pulpwood harvest increases, but inelastic supply implies that equilibrium harvest will be significantly smaller than the demand increase. Planting has a small influence on the feedstocks (Figure 9c), but the impact does not occur until a decade after the biomass demand enters the pulpwood market (BIO 3). The planting impact is muted because low sawtimber prices dominate the rent calculation even when pine pulpwood prices are included. There are larger, more immediate, cumulative impacts from assumed growth increases (Figure 9d, BIO 4). Higher supply leads to increased pine harvest and less displacement. Because plant-

ing response is linked to price changes, but growth responses are not, increased growth lowers the price impetus for increased planting. The combined effect (Figure 9e, BIO 5) is much smaller than the sum of the separate effects (Figure 9c and d).

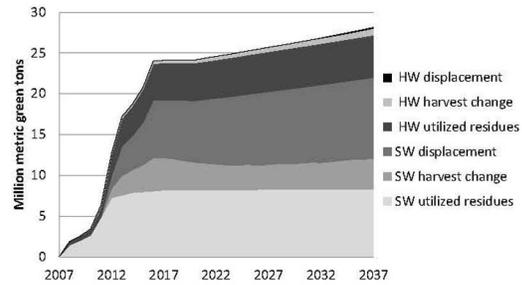
The impact of displacement depends on the relative demand price elasticities for wood by the bioenergy and pulpwood sectors. Figure 10 shows the relationship between pine pulpwood and bioenergy demand projections and the resulting harvest change. In Figure 10a, which has the lowest supply response (BIO 1), the price effect on reduced wood consumption is more than 80% of original biomass demand. In other words, if all of the reduction in sector demand was allocated to the bioenergy industry, less than 20% of announced bioenergy capacity would be built. Alternatively, if the entire displacement was fully absorbed by the pine pulpwood industry, there would be a 40% reduction in projected sector demand. Figure 10b shows the direct impact of LRR increases (BIO 2), and although the effect is immediate, it does not change the path of displacement. Figure 10c and d (BIO 3 and BIO 4) shows the reduction in displacement over time associated with planting responses and growth responses, respectively, and Figure 10e shows the combined responses (BIO 5). These figures also illustrate that although increased harvest directly affects pine pulpwood displacement, the additional residues from increased harvest allow bioenergy displacement to decline faster for a given supply response. With the assumption of similar demand-price responses, both industries would experience a 28% reduction from expected demand based on supply price effects at the end of the projection in the low supply response BIO 1 scenario (Figure 10a). In the high



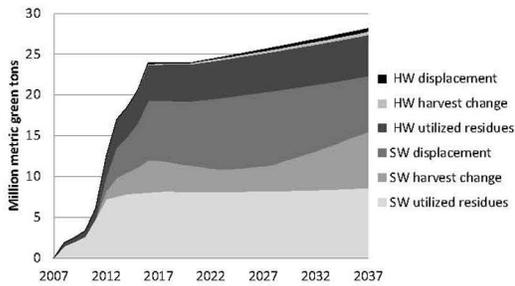
(a) BIO 1—traditional + bioenergy demand; 33% logging residue recovery



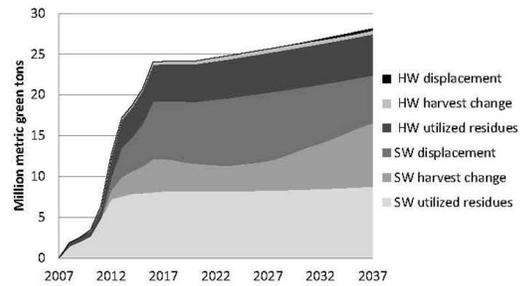
(b) BIO 2—traditional + bioenergy demand; 66% logging residue recovery



(c) BIO 3—traditional + bioenergy demand; 66% logging residue recovery; increased planting response



(d) BIO 4—traditional + bioenergy demand; 66% logging residue recovery; 25% growth increase



(e) BIO 5—traditional + bioenergy demand; 66% logging residue recovery; 25% growth increase; planting increase

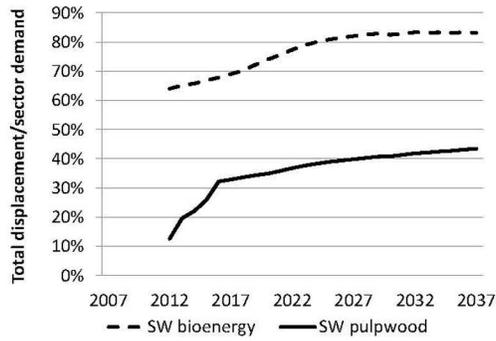
**Figure 9.** Wood use for bioenergy feedstocks from simulations of five bioenergy supply response scenarios showing displacement, new harvest, and used residues by species group for Alabama, Florida, and Georgia from 2007 to 2037.

supply response BIO 5 scenario (Figure 10e), with similar price responses between the sectors, displacement would peak at 19% in 2022 but decline to 12% by the end of the projection when increased growth and planting rates are incorporated into pulpwood supply.

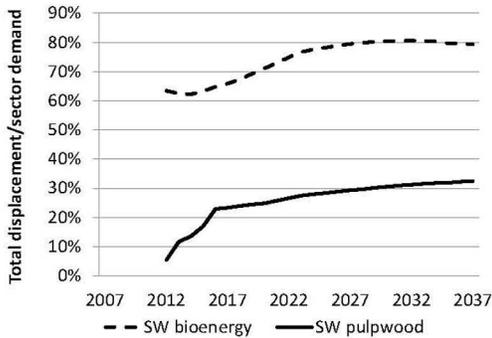
Forest carbon stock is driven by growth, removals, age class distribution, and land use change. The market impacts were concentrated in pine plantations, but they represent only 26% of the initial carbon stock, although the hardwood types (oak-pine, upland hardwood, and lowland hardwood) represent 57%. Figure 11 shows the aggregate on-site forest carbon inventory across all forest types by scenario by year. The total carbon impacts indicate that scenarios where forest rent included pine pulpwood and had net carbon increases over the baseline scenario. Scenarios that linked forest rents only to pine sawtimber prices showed net reductions because the increased harvest was not offset by

additional planting or reduced loss of natural stands to agriculture due to higher bioenergy demand. The difference between BIO 1 and BIO 2, which reflects only higher residue utilization, in BIO 2, shows BIO 2 with small but cumulative carbon advantage over time. This effect is slightly overstated as the reduction in the transient carbon stock in residuals is not estimated. The advantage here is due to decreased harvest of roundwood only. Note the scale in Figure 11: the maximum carbon disadvantage over the baseline is approximately 2% in BIO 4 in the second decade and the maximum carbon advantage over the baseline is approximately 1.5% in BIO 3 and BIO 5 in the first decade.

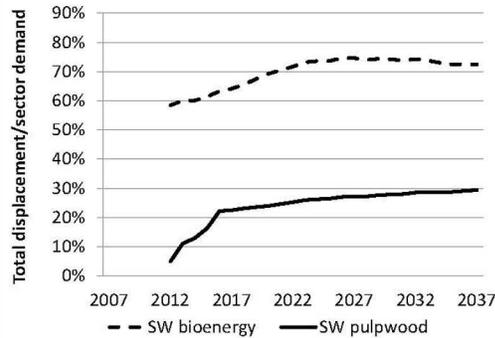
Differences between carbon impacts from plantation growth rate increases (BIO 4 and BIO 5) and land use effects due to forest rents (BIO 3 and BIO 5) are best understood by examining the differential impacts on planted and natural stands shown in Figure 12. As modeled here,



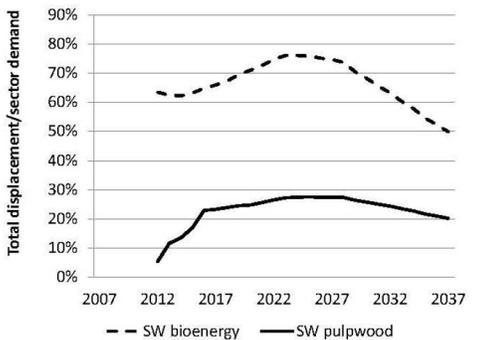
(a) BIO 1—traditional + bioenergy demand; 33% logging residue recovery



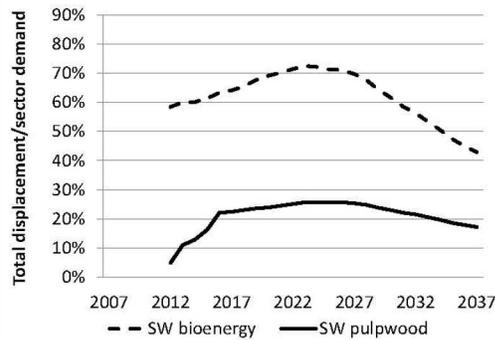
(b) BIO 2—traditional + bioenergy demand; 66% logging residue recovery



(c) BIO 3—traditional + bioenergy demand; 66% logging residue recovery; increased planting response



(d) BIO 4—traditional + bioenergy demand; 66% logging residue recovery; 25% growth increase



(e) BIO 5—traditional + bioenergy demand; 66% logging residue recovery; 25% growth increase; planting increase

**Figure 10.** Range of displacement possible for bioenergy sector and traditional sector resulting from assumptions that all displacement will fall on selected sector from simulations of five bioenergy supply response scenarios for Alabama, Florida, and Georgia from 2007 to 2037.

land use change responds to price, but the growth increase is not price-responsive, which might correspond to a continued trend in genetic improvement. Figure 12 shows that the carbon differences among scenarios are driven primarily by differences in natural stand carbon. Over time, market responses tend to offset changes in supply or demand on plantations. During the recession, fewer acres were both harvested and planted. Although decreased prices led to a loss of plantation acres, the decreased harvest allowed total inventory and carbon to increase slightly. Higher demand leads to increased harvest and price, which reduces the inventory and carbon stock but leads to more planting and intensive management. As shown in Figure 12, this allows

carbon stocks in the plantations with increasing growth rates to exceed baseline carbon by the end of the projection. Planting responses in these scenarios are depressed by continued low pine sawtimber prices. Pine sawtimber is the only rent driver in BIO 1, BIO 2, and BIO 4 but has a greater influence than pine pulpwood prices in all scenarios.

The natural stands are also affected by price in the model. When forest rents rise, the timberland increase relative to agriculture is attributed to pine plantations. With increased rents, however, there may also be less conversion of natural stands to agriculture. No scenario increased timberland at the agriculture margin enough to offset the effect

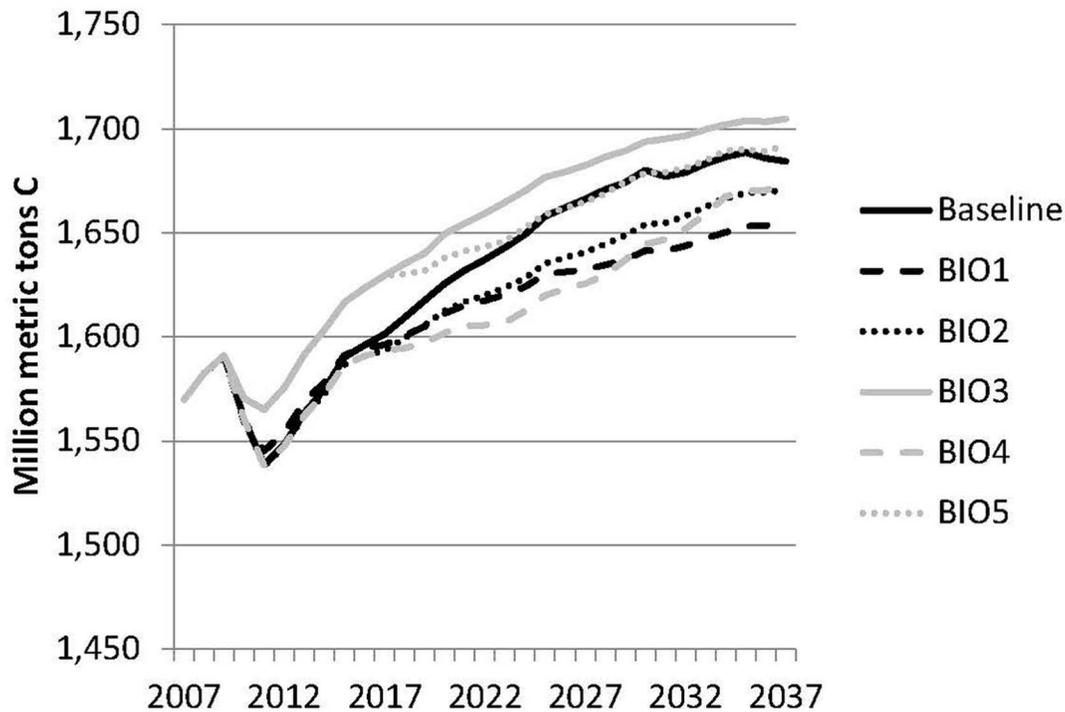


Figure 11. On-site carbon sequestration from simulations of five bioenergy supply response scenarios for Alabama, Florida, and Georgia from 2007 to 2037.

of urbanization, but compared with the baseline run, reduced loss of natural stands has a significant carbon effect. Scenarios BIO 3 and BIO 5, which use forest rents that include biomass price effects on pine pulpwood, lead to less loss in all forestland and an increase in plantations to prerecession levels as described above. This advantage appears before the biomass markets begin because pine pulpwood prices are less affected by the recession in the pre-biomass market period. The BIO 5 scenario, which also includes the higher plantation growth rate, however, begins to lose some of this advantage over time as higher pulpwood inventories lower prices and rents, which lower replanting rates. Scenarios BIO 1 and BIO 4 reduce the carbon stock in natural stands relative to the baseline. In BIO 1 with low residue utilization, natural hardwood stands are harvested to meet bioenergy demand. BIO 4 includes plantation growth increases, but forest rent is linked to only pine sawtimber so that natural timberland is decreasing faster than in other scenarios at the end of the projection.

## Conclusions

Regardless of the forces that create new bioenergy wood demands, there will be impacts on traditional wood-using industries. The magnitude of these impacts, however, will depend on both the level of demand and the level of supply response. The time path and market consequences of the growth and planting responses are quite different, so that although these are the primary levers by which management can influence supply, the scale, timing, and market impacts of all three responses lead to different land use and carbon outcomes. If demand stays at a level coincident with announcements of facilities and if logging residue recovery rates can average 66% or higher across the region, then

market results indicate that the price effect may displace up to 28% of projected demand in the low supply response scenarios or 12% of projected demand in the high supply response scenarios. How this displacement is distributed depends on the wood demand price responsiveness of the emerging industry relative to that of the existing industry.

Higher product prices are linked to land use through the planting response function such that an increase in prices will lead to an increase in new pine plantations. Thus, in scenarios in which prices increase, there is more timberland area than occurs under the baseline scenario without bioenergy demand. This, in turn, leads to a higher level of carbon sequestration in the standing forest than occurs under the baseline. Growth increases, assumed at a regional average of 25% on new pine plantations, lead to an increase in inventory volume that will have a moderating effect on pulpwood prices in the simulations. The regional carbon outcome is lower in the scenario with growth increases than in the scenario with only increased planting response. In all scenarios, including the baseline, the three-state forest carbon sequestration is higher at the end of the projection than in 2007, because carbon in aging existing stands accrues at a faster rate than what is expected to be lost through harvest or conversion to other land uses.

One crucial assumption regarding the market effects of bioenergy demands is the projection of the traditional industries. We modeled as if traditional demand for stumpage would continue to increase at a rate of about 1% per year for sawtimber and 0.5% per year for pulpwood for the second decade and half that for the third decade of the projection. Under an alternative assumption that demands from these industries fall in the absence of bioenergy demands, then prices will fall, potentially leading to declines in timberland

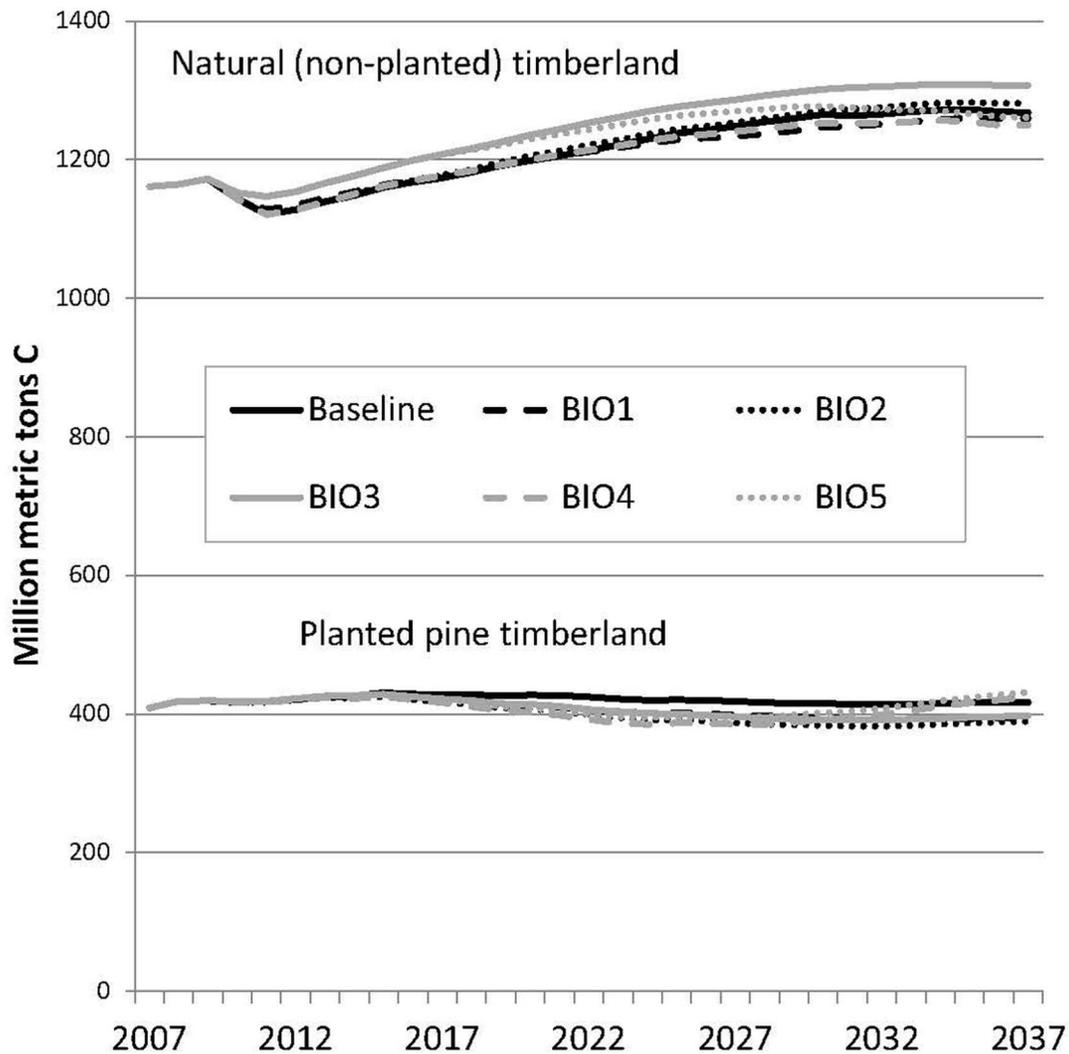


Figure 12. On-site forest carbon sequestration from simulations of five bioenergy supply response scenarios for planted and natural stands for Alabama, Florida, and Georgia from 2007 to 2037.

area and thus in sequestered carbon. Adding in the new bioenergy demands, however, means that declines in traditional harvest will reduce feedstocks available from logging residues, regardless of recovery rates. This, in turn, will lead to higher harvests of pulpwood for bioenergy with resulting price increases for pulpwood and thus smaller declines in timberland area and higher forest carbon sequestration in these three states.

Additional research is needed on the price responsiveness of several of the relationships modeled in the scenarios for which we made assumptions, including residue recovery response to prices, plantation productivity response to prices, and changes in pine plantation conversion from other forest types. Finally, improved carbon accounting would better account for carbon stored in end-use wood products, the carbon dynamics of residue recovery or decay over time, and emissions attributable to shifts in harvest activity outside of the three-state-region. Although we do not expect the inclusion of these components to change the magnitude or direction of our results, it would add additional detail to our estimates and allow for increased scrutiny of those scenarios yielding marginal carbon benefits (e.g., BIO 5).

These results also illustrate the importance of the recovery of pine sawtimber demand in this region. Although a relatively modest plantation growth increase is sufficient to stabilize prices and restore inventories given bioenergy demand examined here, the key forest rent driver of supply response, pine sawtimber price, may be largely unaffected by bioenergy demand in the near term. These factors imply that increased pine pulpwood demand in the absence of pine sawtimber market recovery will increase pressure to use small sawtimber to meet these demands. Further research is needed to investigate how price-sensitive product definitions would affect these results.

### Endnote

[1] An increase in the demand for residues for wood energy has the potential to result in an increased harvest of roundwood, dependent on a complementary relationship between residues and roundwood (either sawtimber or pulpwood), such that an increase in the price of residues (from zero to a positive value) would lead to an increased harvest of either sawtimber or pulpwood. Using a theoretical stand-level model of soil expectation value, a new product such as residues could lead to a small decline of the optimal rotation age, depending on the presence of other costs and the production rates of residues from the different

products (all else held constant). Whether this leads to an increase or decrease in aggregate harvest volumes is dependent on these optimal stand decisions, the number of stands affected, and the ultimate effects on market prices from changes in stand management. We are not aware of any research on the complementarity between roundwood and residues, and little research on the complementarity of the pulpwood and sawtimber. The results from these latter studies (Newman 1987, Newman and Wear 1993, Prestemon and Wear 2000, Polyakov et al. 2010) provide mixed results on complementarity between forest stumpage products.

- [2] According to Timber-Mart South, fourth quarter average southwide prices for pine sawtimber were \$23.54/ton and for pine pulpwood were \$8.20/ton (Timber Mart South 2012).

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