The South's Outlook for Sustainable Forest Bioenergy and Biofuels Production

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Summary. The future of a wood-based biofuel/bioenergy sector could hold important implications for the use, structure and function of forested landscapes in the South. This paper examines a set of questions regarding the potential effects of biofuel developments both on markets for traditional timber products and on the provision of various non-timber ecosystem services. In addition, we examine the key factors that would determine the development of such a sector, especially state and federal policies. A variety of factors will likely affect raw material supply in the region, but landowners have long demonstrated responsiveness to expanded demands for timber. The potential for competition with existing industry appears high. New policies could have the most immediate impact on the structure and size of this new set of demands and there appears to be strong potential for market growth and price increases for raw materials. Potential effects on ecosystem service values are highly uncertain, suggesting that monitoring be emphasized as these developments progress.

Keywords. Bioenergy, resource policy, environment.

Introduction

The South would likely play a substantial role in a new wood-based biofuel/bioenergy sector in the United States. The region has demonstrated strong comparative advantage in the production of a variety of wood products and is now the largest producer of timber in the United States. It could also have a strong comparative advantage in the provision of raw material for biofuels given high biological productivity, a dominantly private and intensively managed timber resource, a well-developed infrastructure—from logging through transportation to processing—along with the largest potential source of residues in the country. In a sector governed strictly by market forces, a cost-competitive biofuels sector would likely emerge in the South.

Questions remain however, regarding how the rapid development of a new sector would play out in the forest sector of the region. The existing wood consuming industry in the South provides a strong competition for the wood resource, so we might ask how much of new fuel feedstocks would derive from roundwood (whole harvested logs) instead of from residuals generated by current logging and production processes. How would the increased demand for wood for energy affect the markets for existing wood products? Any increased competition for raw materials would provide a signal to timberland owners to increase their investments in timber growing and therefore to expand supplies but how long would it take to realize such an expansion?

Other questions need to address the impacts of potential policies on the sector. A wood-based bioenergy sector is unlikely to emerge based on its financial returns but would initially depend on substantial government intervention. Policies that would subsidize the use of wood for bioenergy

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could cause a structural shift in the demand for raw materials in the region. How would this market distortion play out within the current wood-using production base? Who would lose and who would gain from these various policies?

Yet another set of questions asks about the potential impacts of this new sector on environmental objectives, the non-timber ecosystem services provided by the region's forests. How might the emergence of a large wood-based bioenergy sector affect water quality, biodiversity, and carbon stocks in the region? How might policies be designed to safeguard ecosystem services?

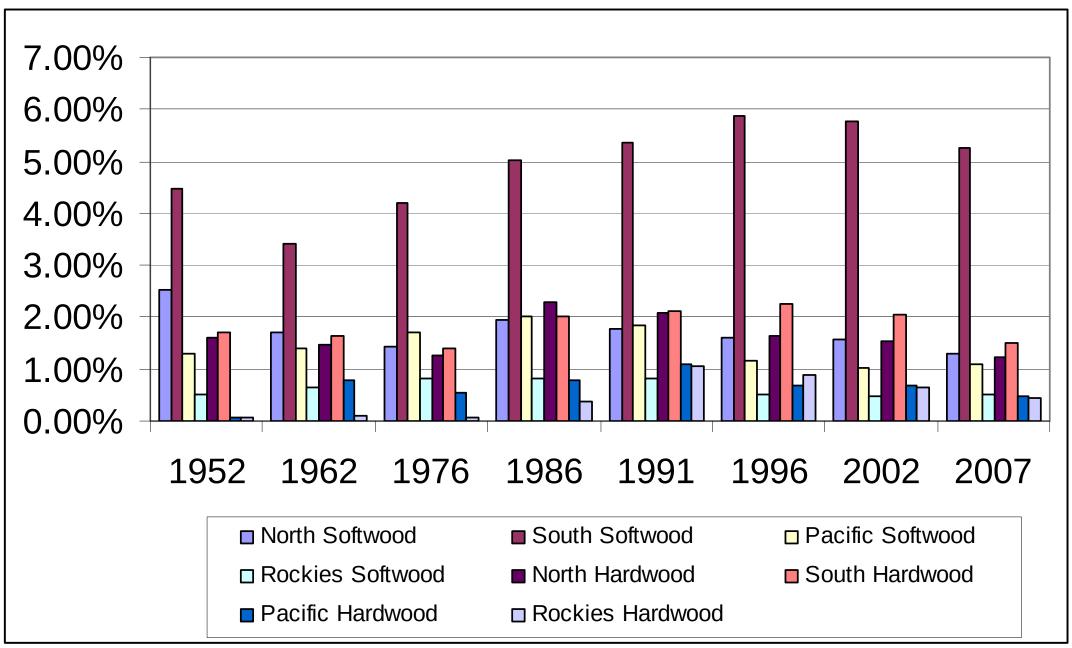
This paper does not answer all of these questions. Rather it is intended to pull together available information regarding the potential development of a wood based bioenergy sector and set the stage for further discussion. Our intent is to define the potentially important issues surrounding the development of bioenergy policies and to set the context for evaluating future bioenergy developments in the South.

Forest Resource Situation in the South

Current inventory and use

The Southeastern United States has a large and varied endowment of forest resources and provides more than 60 percent of the nation's timber production. In 2005, the region produced 11.9 billion cubic feet of various roundwood and residual byproducts (Johnson et al. 2008), including 6.4 billion cubic feet of softwood roundwood and 2.3 billion cubic feet of hardwood roundwood. Of the total roundwood produced in 2005, 40 percent was used for pulpwood while 45 percent was used for sawlogs. 3.2 billion cf of residual byproducts were also used in a variety of production processes.

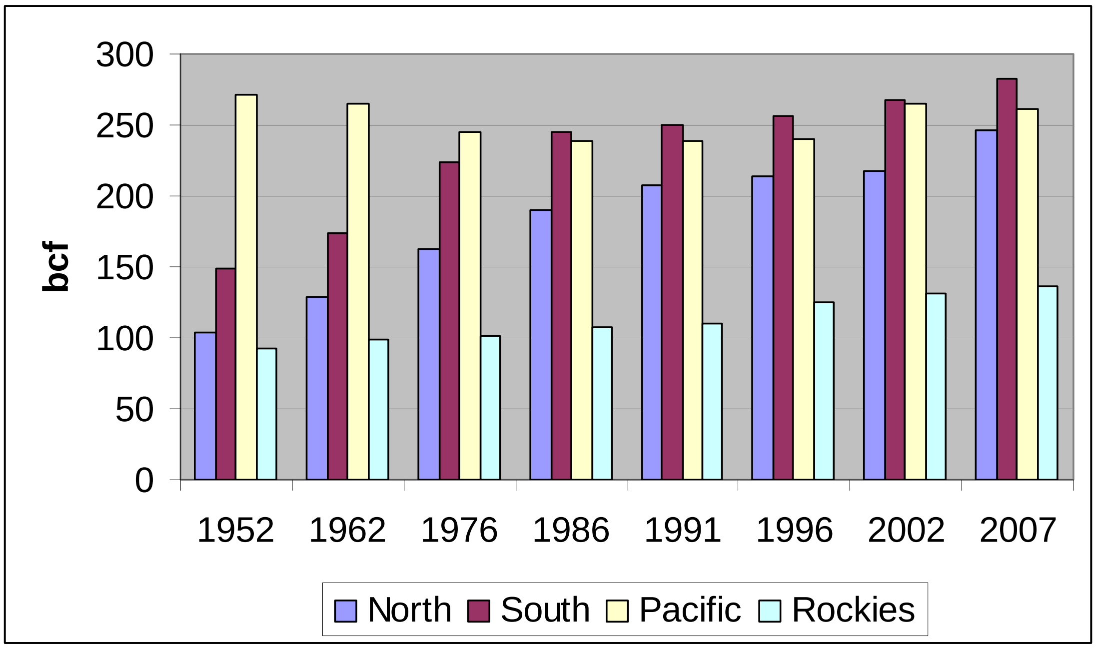
Figure 1: Timber harvest intensities for regions of the United States, 1952-2007. Harvest intensity is defined by the ratio of timber harvests to growing stock inventory on timberlands within the region.



This level of production makes the South the most intensively managed timber resource in the United States. The rate of harvesting for softwoods (measured as the removals: inventory ratio[7]) has ranged between 5 and 6.5 percent since the 1980's (Figure 1). In comparison, the softwood harvest rate was between 1.2 and 1.5 percent in the northeastern U.S. and between 1 and 1.9 percent of inventory in the Pacific Northwest over this same period. Hardwood harvest rates are also highest in the South ranging from 2 to 2.4 percent of inventory since the 1980's. The only other large hardwood producing region is the northeastern U.S. where production rates ranged between 1.1 and 1.3 percent of inventory over the same period.

Production rates grew in the South as the area of intensively managed forest land increased from nearly zero in the early 1960s to between 17 and 20 percent of timberland in the region today. This intensification of management allowed standing inventories to expand or remain stable while output grew between the 1970's and the 2000's (Figure 2).

Figure 2: Total growing stock inventories in forests by region of the United States (1952-2007).



Resource supply

Aggregate timber supply defines the relationship between timber production and its market price. It derives directly from the propensity of forest landowners to harvest their timber given current and expected market conditions and is influenced by the growth rate of the stand as well as the preferences of individual landowners. In the short run especially, timber supply is largely shaped by the quality and vintage distributions of existing forest inventories.

The South contains a large quantity of intensively managed forest land and private landowners of various types have been willing supply timber to the market. What's more, over the long run, private landowners have demonstrated a willingness to invest in and expand timber supply to meet anticipated demands. Looking forward, we evaluate trends in land use, forest productivity,

[7] Define the data sources etc… for the harvest rate calculations.

and forest ownership and how they might affect future timber supplies (based largely on Wear et al. 2007).

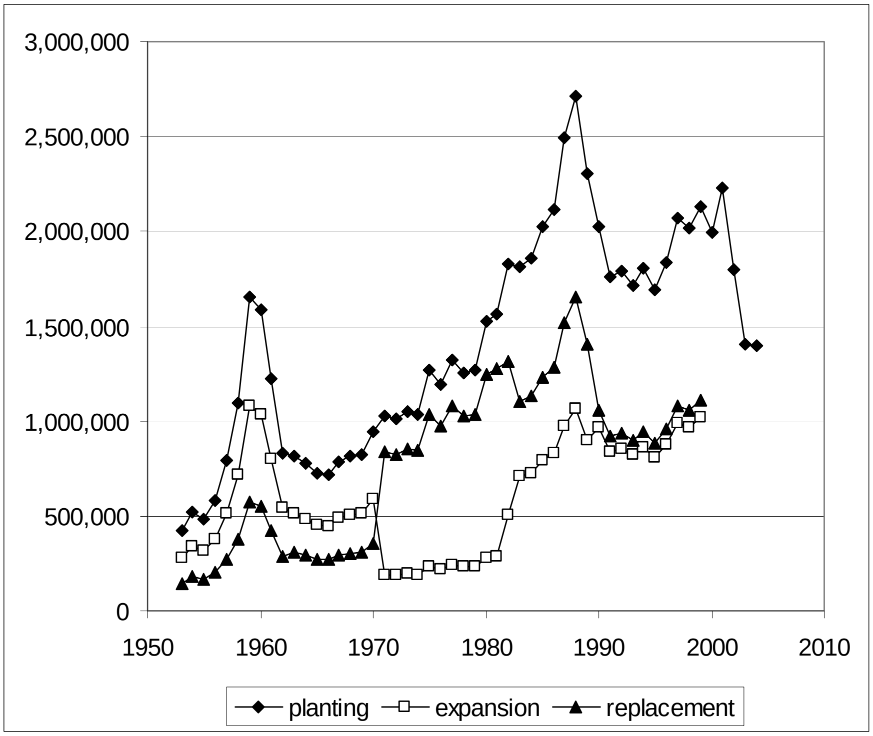
Competing Uses of Land: Total timberland area in the South was relatively stable throughout the 20th century except for about a 5 percent reduction in the 1970s tied to agricultural expansion. Offsetting changes were behind this stability, however, with decreases in forest area associated with urbanization and simultaneous increases in forest area reflecting shifts from agricultural uses. Net forest losses since the 1950's were greatest in Texas, Florida, Oklahoma, and Louisiana. Alabama, Georgia, Kentucky, Mississippi and South Carolina saw the largest gains in forest area over this period as agricultural production shifted westward and southward within the region.

Forecasts of future timberland in the South (Wear and Gries 2002) suggest that urbanization in the eastern part of the region (especially along the coasts and the Southern Appalachian Piedmont) will continue to consume timberland. Depending on the market for various agricultural products, some crop and pasture land could be converted to forests in the western parts of the South, especially in the Mississippi valley. Forest loses could range from zero (a no net loss scenario) to more than 30 million acres (roughly 15 percent of existing timberland) between 2000 and 2030.

Forest Types: Perhaps just as important for evaluating timber supplies is the distribution of forest types. The region has a broad diversity of forest types with two major subdivisions: naturally-regenerated and planted. Naturally regenerated lands, including hardwoods, pine, and mixed pine-hardwood forests, are largely a residual land use—located where neither urban or agricultural uses can be justified. Plantations, on the other hand, represent a purposeful accumulation of capital developed with the intent of producing timber. Plantation forestry is an agricultural style of production and has expanded considerably in the South.

Pine plantations grew steadily from practically none in 1950 to more than 30 million acres in the late 1990s (Wear and Greis 2002). They now account for more than 16 percent of all timberland in the region (Figure 3). These forests can produce up to three times as much timber as naturally regenerated forests and therefore the area of plantations has an important role in determining the supply of timber from the region. There is strong indication that the area of planted forests has leveled off over the past five years, but there is potential for further expansion in response to scarcity signals.

Figure 3: Forest planting in the US South (1952-2002).



Forest Ownership: Private owners control eighty nine percent of roughly 200 million acres of timberland in the South. Research into the economics of timber management has identified important distinctions in the management of forests by different types of owners (e.g., Newman and Wear 1993, Pattanayak and others 2004). In the 1990s these studies showed that forests owned by forest industry were much more productive (with respect to timber output) than all other land owner types. While the industry held 20 percent of the forest land, they accounted for roughly 60 percent of the plantations. While other owners have produced a large portion of the timber harvested since the 1950s, the investments made by the forest industry had perhaps the largest impact on expanding the supply in the South.

Since 1999 much of the forest industry timberland has been sold to new, largely institutional, investors. How might this affect future supply? The largest share of these lands is now managed by Timberland Investment Management Organizations (TIMOs) and many of their investments are tied to closed-end funds that tend to trade frequently. As a result we might expect more rapid turnover in these lands and possibly splitting into smaller and smaller parcels. While TIMO's have strong incentive to maximize returns through both harvests and capital improvements in forests, one might argue that management will utilize a shorter time horizon (and be more sensitive to short run changes) and that timber inventories will be less stable with this large shift in ownership. The result would yield somewhat more volatility in timber prices in the region. Questions remain regarding the implication for future growth or contraction of timber supply in the South.

What does all of this mean for future timber supply? Current timber supply and supply over the next 10-20 years will be largely determined by capital in place. Our analyses of supply (e.g., Wear et al 2007; Abt) indicate that supply will expand in much of the South over the next two decades based on the intensification of management and increased planting through the early

2000s. We have raised some uncertainties regarding these supplies based on land use change patterns and ownership changes. Land use changes will be concentrated and may alter production at specific locations in the short run and changes in ownership would play out over a long time period. Previous episodes of land use change indicate that crop prices can have important effects on the area of forests and increased demands for grains for bioenergy production would dampen expansion of forest areas. Thus the countervailing impacts of bioenergy developments and feedstock demands on land uses remain a key uncertainty.

Resource demands

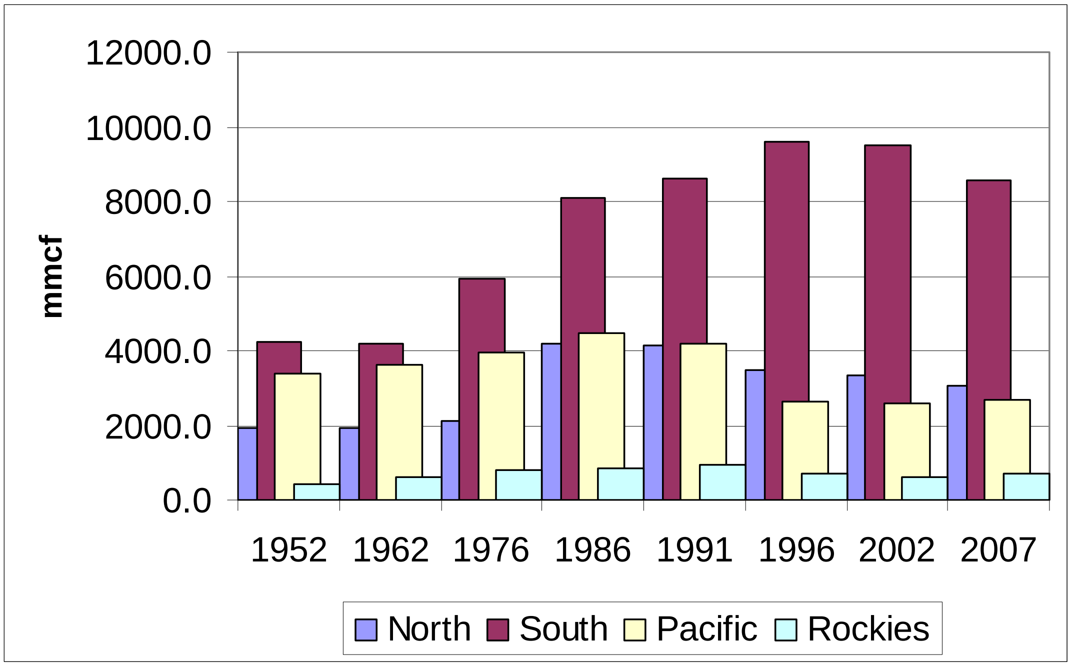
The South's timber sector is characterized by a complex set of demands for wood resources. Production spans paper to solidwood products and, while a majority of output is derived from softwoods, the region produces a large portion of hardwood products. This sector has evolved over a long period with especially rapid development from the 1970s through the 1990s (Wear et al 2007).

The paper industry represents more than 40 percent of timber consumption in the South and the locations of clusters of pulpmills define concentrations of pulpwood demand. While satellite chipmills distributed the demand for pulpwood over more of the region in the 1990s, pulpwood markets are still concentrated geographically. In addition to pulpwood, paper producers consume a large share of residuals from other wood production processes (e.g., lumber and plywood) in the South. The size of the paper sector in the South (measured by pulpmill capacity) expanded from the 1980s through much of the 1990s, peaked in 1998 and has since declined by about 16 percent (Wear et al. 2007). While the South continues to lead the world in pulping capacity, its share of the world paper market has declined and there seems to be little indication that it is set to expand in the foreseeable future.

Lumber and panel products represent about 46 percent of fiber products generated in the South and these mills are widely dispersed across the region (Wear et al. 2007). The most recent data indicate that sawmill capacity remains at historical highs. The largest source of growth in solidwood has been the production of panels, with especially strong growth in the production of fiberboard and, to a lesser degree, oriented strand board. Plywood production has leveled off and begun to decline (Wear et al. 2007).

Overall, total timber production more than doubled between the late 1960s and the 1990s in the South while production in other regions of the country declined (Figure 4). The comparative advantage of the South was expanded through changes in technology that favor use of small diameter and lower quality timber—e.g., paper, fiberboard, and oriented strand board. Since the late 1990s, the sector has experienced an adjustment phase that halted this unprecedented 30-year expansion. Wear et al. (2007) attribute this structural change largely to declines in domestic demand and find evidence that supply has continued to grow during this period.

Figure 4: Timber production by region in the US.



What are the implications for biofuel feedstocks? While demand for pulpwood in paper manufacturing has declined slightly and leveled off, demand for the same material in panel products has grown. In contrast demand for sawtimber has remained strong (though facing short run declines due to the recession). A large share of residuals from solidwood production processes are currently captured in other production process—e.g., paper. Logging residuals remain untapped, but the amount of recoverable residuals is unclear. Overall, the demand for southern timber is expected to be strong, so any new industry would compete directly with other industries for raw material, resulting in upward pressure on raw material prices.

Outlook for bioenergy and liquid biofuels applications

Analysts seem to agree that cellulose-based liquid biofuels are not currently feasible based on production economics. Costs per energy content are very high compared to petroleum and even to grain-based biofuels. In contrast, combustion of wood to generate energy has a long history and has seen some growth in the South recently but there appear to be important constraints to substantial scaling-up of these cofiring operations (English et al. 2004).

The outlook for bioenergy is not, however, based on comparative production economics, but on goals related to energy security and, to a lesser extent, environmental quality. Policy initiatives pursuant to these goals will play a foundational role in the development of bioenergy markets. As with grain-based ethanol, government subsidies or source requirements such as Renewable Portfolio Standards could support the development of this sector absent cost competitiveness. The push for ethanol is most visible in the Energy Independence and Security Act, 2007 which calls for replacing 36 billion gallons of gasoline with biofuel by 2022. Out of this total 15 billion gallons is expected to come from starch based ethanol; 21 billion gallons from cellulosic sources.

Current bioenergy situation

Biomass based energy is a key renewable energy source in all thirteen southern states. Electricity and liquid biofuel generated from biomass in the region is about one fifth of the total in the country.[8] Plans are in place for expansion in both liquid and non-liquid biofuels in the South.

Bioenergy from liquid sources: Liquid biofuel production plants produce ethanol or biodiesel for transportation fuels. Since corn is currently the main feedstock for ethanol production in the United States, most of the ethanol production plants are located in the Midwestern states. However, there are a number of grain-based ethanol plants operating in the southern region.

At present there are no cellulosic conversion ethanol plants operating on a commercial basis in the region. Two plants are under construction and plan to use wood or other cellulosic feedstock for ethanol production. One is the Range Fuels plant in Georgia that will use a thermo-chemical cellulosic conversion process; the other is the Verenium plant in Florida that will use a biochemical process. Meanwhile, a small cellulosic ethanol plant in Florida is planned. This research and demonstration plant is being built on Florida Crystals Corporation's Okeelanta plant in southern part of the State.

The Range Fuel Plant at Soperton, Georgia would be the first in the country to produce commercial quantities of ethanol from cellulosic biomass. The company plans to utilize wood residues left after timber harvesting in production of about 20 million gallons of ethanol and other alcohols per year, initially. At full-scale operations, the plant is projected to produce up to 100 million gallons of ethanol each year.[9]

There are eight companies in the region producing biodiesel fuel that are listed as members of the National Biodiesel Board (NBB) and accredited as BQ-9000 producers. In addition, there are about 70 NBB-listed producers/marketers in the region.[10]

Bioenergy from non-liquid sources: There are more than fifty power plants in the South that utilize various biofuels to generate heat and/or electricity. Electric power plants in the South generated more than 25 trillion watt hours of electricity from biofuel sources in 2007. The states of Alabama and Florida generated about 4 trillion and 4.4 trillion watt-hours of electricity from biofuels, respectively, while Georgia and Louisiana each generated more than 3 trillion watt-hours.[11]

Co-firing of biofuels with fossil fuels such as coal reduces pollutant gases outflow as compared to fossil fuels alone. An existing power plant facility can be used to blend biomass (up to 5%) with coal or to inject biomass separately (up to 20%) into the boiler. Co-firing of biomass with coal provides environmental returns by reducing SO_2, NOx, and CO_2 emissions but also generates costs associated with ash deposition, corrosion, and carbon burnout. The procurement and process of cellulosic feedstocks provides another challenge especially given the variability and high moisture content of biomass feedstocks (Hughes, 2000; Tillman, 2000; Cobb and Elder,

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8 Energy Information Administration, 2008. Renewable Electric Power Sector Net Generation by Energy Source and State, 2005. Accessed on April 30, 2008.
<http://www.eia.doe.gov/cneaf/solar.renewables/page/rea_data/rea_sum.html>
9 http://www.rangefuels.com/our-first-commercial-plant. Accessed on November 2, 2008.

10 http://www.biodiesel.org/buyingbiodiesel/producers_marketers/. Accessed on October 25, 2008.
11 U.S. Department of Energy, The Energy Information Administration (EIA), EIA-906/920 Fuel Stock Data for Electric Power Sector Generating Facilities, 2003-2007.

2000). Currently there are 24 electric power plants in the region with the flexibility needed to co-fire biomass together with fossil fuels. Twelve of these units are currently cofiring.[12]

Wood fuel pellets define another bio-based fuel that has grown substantially in the South. There are a total of 18 pellet fuel manufacturers in the region. Arkansas with five has the highest number of pellet fuel manufacturers in the southern U.S., while Georgia has four, Kentucky has three, and Mississippi has two pellet manufacturing facilities.[13]

Wood products sector: The largest producer and consumer of cellulose-based biofuels in the region is the pulp and paper sector. Black liquor, a liquid byproduct generated by kraft pulp mills, can be burned to generate electricity for plant operations or for the grid. This process generates enough electricity to provide about 54 percent of the power needs for this energy intensive sector (DOE). Black liquor has recently been seen as a potential source of hydrocarbon based fuels and other fuels, but these developments would involve the redirection of a currently viable cellulose-based bioenergy source. Solid residuals from wood products manufacturing have also been burned to generate substantial amounts of energy for production processes.

Bioenergy infrastructure: Infrastructure for delivering fuels to customers is an important element in the successful development of a bioenergy sector. Infrastructure has evolved rapidly with grain based transportation fuels, and we might expect it to respond further to the emergence across a broader portion of the region. There are a total of 1,950 alternative fuel stations in the region, of which 1,208 dispense E85 (85% Ethanol, 15% Gasoline) and 742 provide biodiesel.

Transportation infrastructure is well-developed in the South. At present 47,486 miles of railroads are present in the region and they play an important role in moving commercial goods from one place to another.[14] The total length of federal highways present in the southern states is about 31% of the total nation i.e. 304,208 miles. Similarly, total length of non-federal highways is about 955,911 miles which is again about 31% of the total length of nonfederal highways present in the nation.[15]

Forest biomass resources/feedstock: A biophysical analysis of feedstocks (Perlack et al. 2005), estimates that approximately 368 million dry tons of biomass might be produced every year from forest resources in the U.S. The South's 214 million acres of forestland (Wear and Greis 2002) is highly productive resource that could be tapped for more production. This is reflected in forest based biomass production of the region which accounted for about 70% of the nation's total forest biomass harvested in 2001 at--i.e. about 9 billion ft^3 (Wear et al., 2007) Forest sources that might be used for energy include harvest residues, small diameter (thinning from traditional forest management and fuel treatments), residues from mills, bioenergy plantations, stands damaged by natural disturbances (fire, windstorm, pest outbreaks, and etc.), stand degraded by poor logging practices, and urban wood wastes[16].

Logging residues are seen as an important potential source of forest biomass for bioenergy. These mainly involve utilizing the unused portions of trees, such as branches, left on site after cutting.

12 This section has been drawn from Alavalapati, J.R.R., Hodges, A.W., Lal, P., Dwivedi, P., Rahmani, M., Kaufer, I., Matta, J.R., Susaeta, A., Kukrety,S., Stevens, J.T..2008. Bioenergy Roadmap for Southern States, (SAFER Draft report).
13 Pellet Fuels Institute, http://www.pelletheat.org/3/residential/fuelAvailability.cfm#south
14 Association of American railroads, 2008. Railroads and states. Accessed on October 25, 2008. <
http://www.aar.org/IndustryInformation/AboutTheIndustry/RailroadsAndStates.aspx>
15 Federal Highway Administration, 2008. Policy Information. Accessed on October 25, 2008.
< http://www.fhwa.dot.gov/policyinformation/index.cfm>
16 http://forestencyclopedia.net/p/p2

Perlack et al (2005) estimate that around 40 million dry tons of these residues could be harvested annually with over 90% coming from privately owned lands.

Other sources of forest bioenergy feedstocks might include small diameter trees from fuel treatment thinnings and killed and damaged timber from natural disturbances (e.g., hurricanes, tornados, wildfires and pest and disease outbreaks). Coulson et al. (2005) estimated that an average 1.36 million tons of biomass is killed annually by the Southern Pine Beetle alone in eleven southern states (see also Mayfield et al. 2008). However, the location of killed timber varies considerably from year to year and may not correspond with the production infrastructure necessary for harvesting and hauling the material.

Short rotation woody crops (SRWC), for example willows and poplars, could also be an important supply of woody biomass. Perlack et al (2005) estimated that about 5 million dry tons of biomass from SRWC plantations might be produced for bioenergy purposes annually in the U.S, a significant portion of which would be from the South. However, landowners have yet to invest in the SRWC technology in any substantial way, suggesting that higher market prices and market certainty are needed before adoption would commence.

Urban wood residue feedstocks: Yard wastes and construction wastes could be yet another source of biomass. These vary in quality: construction scraps have high quality biomass while demolition materials suffer from various forms of contamination. According to Perlack et al (2005), a total of 28 million dry tons could be gathered from urban sources in the U.S. There were more than 8 million dry tons of urban wood residues in the southern U.S. in 2005 (Milbrandt 2005).

Industrial byproduct feedstocks: Industrial byproducts like mill residues are another, and one of the most readily available sources of bioenergy. Southern states produced 50.8 million dry tons of mill residues and 23.76 million ton of mill residues fuel byproducts.[17] However, Perlack et al. (2005) finds that around 97% of primary wood processing mill residues are already being utilized. Hence, only small amounts of mill residues could be further diverted for new bioenergy sources without impacting other parts of the wood products industry.

Feedstock supply: Biophysical analysis of feedstock availability helps to scale expectations regarding a wood-based bioenergy sector in the South. However, translation from biophysical estimates of feedstocks to supply estimates involves applying harvest models that account for landowner preferences for harvesting versus retaining timber. These decisions are affected not only by timber economics but also by demands for aesthetic, recreational, and other uses of forest land. Short and long run supply will need to account for ownership dynamics, forest inventory structure, competing land uses, and other demands for fiber products. In addition, byproduct feedstocks (logging, industrial, and urban residuals) are not costless materials. Rather the supply of these feedstocks will depend on the cost structure of gathering and transporting the material to bioenergy processing centers.

Timber supply models (e.g., Newman, Newman and Wear, Polyakov et al) indicate that short run pulpwood supply in the US South is highly inelastic. That is, large price changes are required to bring additional material to market over a five year period. However, supply in the longer run (say ten to twenty years) is potentially much more elastic, as forest managers have the

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17 Source: USDA-Forest Service, Forest Inventory and Analysis, Mapmaker 3.0 online data retrieval system.

opportunity to expand the size of timber growing operations in the region (Wear and Newman). Abt's (2009) analysis of bioenergy scenarios for North Carolina and Georgia amplify these observations—energy demand anticipated by Renewable Portfolio Standards and announced biofuels plants would likely generate substantial price increases for wood products throughout the region.

Key factors influencing bioenergy development

The future of bioenergy development will be influenced by both demand and supply issues and, perhaps most critically, by policy initiatives. On the demand side, the future will depend on the strength of energy demand in the region and around the world as well as on the development of new technology for converting raw material into energy products. On the supply side, the issues are focused on the supply of wood material—i.e., the relationship between the level of timber production and price—and of competing raw material inputs. In the long run some of the fundamentals can change—e.g., landowners may plant new woody crops—but current conditions will dictate much of the possibilities in the short to medium runs. Before these fundamentals develop to make biofuels/cofiring competitive with traditional sources, policy initiatives will likely determine how these markets develop.

Energy Demands: Demand for bioenergy depends on the overall demand for energy and this competitiveness with other sources of energy. Electricity demand in the South has been trending upward with increases in all states. The total consumption of electricity in the southern states was about 1,301 million megawatt hours in 2006.[18] These states accounted for ~35% (EIA, 2008a) and ~31% (EIA, 2008b) of the total electricity and gasoline consumed at the national level in 2007 and 2006 respectively. Increasing oil prices with expanding demand would put upward pressure on the demand for bioenergy.

Technology and economics: Ethanol production from wood at a commercial scale will depend on new technology to improve the efficiency of converting cellulose to bioenergy. It is currently very expensive to break down cellulose, the woody parts of plants and trees, into simple sugars (Orts et al., 2008). Analysts seem confident that improvements in the conversion process are likely to emerge in the near future but the development of new technologies that support production at a commercial scale must be considered highly uncertain (Childs and Gradley 2007). Research is progressing on several fronts.

Cost competitiveness will depend on technological innovation but will also be determined by the costs of all feedstocks. It will also determine the comparative utility of woody biomass versus other feedstocks (i.e., herbaceous perennials such as switchgrass and annual stocks (i.e., corn stover). While logging residuals and some manufacturing residuals may provide a low-cost feedstock for a small sector, scaling up to levels, for example, anticipated by the Billion Ton Study, would quickly involve whole-tree harvesting and therefore competition with existing wood products industry. This competition would necessarily drive up prices for feedstock within the region which should influence the eventual size of the sector. Ultimately we face the question of defining the structure of feedstock supply within this broader sector context. In other words, the relationship between feedstock consumption and feedstock price is not yet well-defined.

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18 Energy Information Administration, 2008. Net Generation by State by Type of Producer by Energy Source. Accessed on April 15, 2008. <http://www.eia.doe.gov/cneaf/electricity/epa/epat1p1.html>

Policy: Interest in developing biofuels from cellulosic sources comes primarily from policy goals, namely (1) energy independence with development of a domestic renewable fuel source, (2) easing of pressure on agricultural markets by providing an alternative to grain-based biofuels, and (3) reducing the environmental footprint of transportation and electricity generation, primarily through reduction in greenhouse gas emissions. Market-scale cellulosic bioenergy is not currently economically viable. While technology, demand, and supply factors might eventually adjust to allow biofuels to compete, either price subsidies or quotas defined by federal and state policy initiatives would drive development of such a market.

Government policies are essential in the expansion of bioenergy operations. The policies provide substantial support to second generation biofuels so that they can compete with gasoline and conventional diesel. These supports include consumption incentives (fuel tax reductions), production incentives (tax incentives, direct subsidy, and loan guarantees), along with mandatory consumption requirements (Childs and Gradley, 2007; World Bank, 2007).

Federal Policy: A wide variety of policy initiatives at the federal level may affect investment in and production of biofuels and bioenergy. Grant programs are being used to accelerate research and development and the construction of renewable energy operations (e.g., 2008 Farm Bill) and production incentives aimed to shift electricity generation to renewables. In addition, a variety of tax provisions encourage the development of renewable resources, including accelerated depreciation for bioenergy investments (e.g., Energy Independence and Security Act of 2007), business energy tax credits and production tax credits.

Significantly, the Energy Independence and Security Act of 2007 also developed a definition for "renewable biomass" that provides limits on the availability of biomass from federal and non-federal land as it contributes to achievement of a national Renewable Fuel Standard (RFS). Certain prohibitions are placed on the utilization of forest plantations, old-growth forests, and forest ecosystems considered to be "imperiled." The policy debates on that definition have also extended into discussions on criteria for potential Renewable Electricity Standards (RES) such as federal mandates requiring states to prepare biomass utilization assessments and landowners to file certified management plans for biomass destined to energy producing facilities. The extent to which current RFS criteria and proposed RES stipulations will impact biomass supply and market dynamics is still to be determined. But, it may be expected that such limitations on supply could be significant at least in certain regions.

The Farm Bill, passed in 2008, begins to shift federal emphasis toward cellulosic ethanol production through a variety of programs. Perhaps most important for forest bioenergy, is a production tax credit of $1.01 per gallon for cellulosic biofuels through 2011. Walsh et al. (2000) found that at a market price of <$30 per dry ton delivered, the total amount of forestry feedstocks available (excluding wood obtained from urban areas but including forest mill residues, dedicated forestry crops, and forestry residues) would be approximately 24% of all cellulosic biomass available in the nation. However, at a market price of <$40 per dry ton delivered, the amount of available forestry feedstocks would jump to 45% of the total cellulosic feedstocks available at the national level. Comatas and Schumacher estimate that 86 gallons of advanced biofuel wight be achieved per dry ton of forest biomass (depending on the technology applied) and that a production tax credit of $1.01 per gallon[19], would yield a feedstock equivalent subsidy of $86.86 per dry ton of forest biomass. This subsidy exceeds the current price paid for most pulpwood consumed in the South. Depending on the comparative costs of labor, energy, and capital inputs

[19] Food, Conservation and Energy Act of 2008 H.R. 6124, Sec. 15321

to producing bioenergy or wood products, the production tax credit could be substantial enough to expand the demand for woody feedstocks.

Interestingly, Title XV-Trade and Tax provisions (Section 15322) of Farm Bill (Section 15322) also authorized the Secretary of the Treasury in consultation with other agencies to enter into an agreement with the National Academy of Sciences to produce an analysis of current and future biofuel production, regional forest inventories, and effects on fuel price, land use dynamics, price of land, and environmental impacts. Among other issues the study will also examine the impact of the tax credit on "silvicultural capabilities of commercially available forest inventories." A Report of initial findings is expected in early 2009.

State Policy: States are also utilizing a variety of tax and production incentives to encourage use of renewable energy. Production requirements may, however, provide the greatest impetus for expanding the utilization of woody biomass. Renewable Portfolio Standards (RPS) require electricity providers to obtain a minimum percentage of their power from renewable resources, including wood. At this time only two southern states have adopted RPS. North Carolina's RPS starts with three percent in 2012 and increases to 12.5 percent of retail sales in 2020. In Texas, RPS would require 5 percent by 2015. While renewables may come from a variety of sources, Abt (2009) finds that wood would likely be the preferred feedstock for electricity generated in North Carolina for the foreseeable future.

The potential effects of various policy approaches are not fully known. Given the large variety of policy instruments, the potential for policy interactions is high and the question of relative efficacy is unanswered. Policies designed to encourage new activities may also ignore ongoing activities. This may set out a perverse incentive to displace one renewable energy operation with another. For example, energy generated by the wood products industries may or may not be subject to favorable treatment by subsidies or accounted for in renewable portfolio legislation. One could imagine cases where the RPS would lead to countervailing changes in the total production of energy from renewables by favoring one process over another.

Feedstock markets: An analysis of various wood feedstock demand scenarios by Abt (2009) suggests that residuals would play a relatively minor role in supplying bioenergy operations in the short-run. Rather, new demands, based on North Carolina's enacted and Georgia's proposed Renewable Portfolio Standards, and on announced biofuel plants in the South suggest that roundwood would soon be tapped as a feedstock. The impact of this new demand depends on (1) location of the bioenergy facilities, and (2) assumptions regarding the price sensitivity of bioenergy producers. If we assume that, because public utilities are driven by policy mandates and their demand for wood biomass is not price sensitive, then resulting market adjustments reduce the size of existing wood products industry in the South. Because of anticipated land use changes and existing inventories, Abt also finds that local markets are variable in their ability to absorb new bioenergy production. For example, he finds more room for expansion in the coastal plains of Florida and Georgia than in North Carolina, where forest losses affect the availability of future supplies.

Implications of a regional bioenergy sector

Interactions with the wood products sector

The wood products markets of the South are both diverse and deep and represent a 50-year co-evolution of industrial capacity and timber production. Market forces have almost exclusively shaped a sector that increased its share of world wood products from 6 to 16 percent of the world total since the 1960s. A strong increase in demand for wood for biofuels (potentially driven by

policy initiatives) could lead to disruptive structural changes in the sector, in effect leading to a substantial increase in the demand for scarce raw materials used by the existing wood products sector.

Comatas and Shumaker (2009) explore the potential impact of a new bioenergy sector on the current industries that utilize wood as a raw material input. They estimate that, because of the established supply chain, relative cost and supply of wood, and consistency of wood's material characteristics, it is reasonable to expect that renewable energy markets would select wood as a preferred biomass feedstock. They examine three sources of new energy demands for the South: (1) "Biomass Export," assumed to support renewable energy requirements of Kyoto Protocol member nations and based on current production levels; (2) "Biomass Electricity," assumed to meet a 15% renewable electricity portfolio standard; and (3) "Cellulosic Ethanol," assumed to equal the South's potential share of the national advanced biofuel goal (see Comatas and Shumaker for details).[20]

For their analysis, new biomass supplies available in the region were assumed to be consistent with the "moderate crop yield increase with land use change" scenario of the *Billion-Ton Annual Supply* (Perlack et al. 2005). These supplies essentially fit into four resource groups: (1) forest residues, assumed to be excess standing timber, debris from harvesting operations, and excess mill residuals, (2) urban residues, assumed to be wood residuals available in municipal solid waste streams or from construction and demolition debris, (3) agricultural residues, assumed to be excess agricultural crop yields, the biomass residuals of crop management, and any secondary or tertiary residues, such as manure or food waste, and (4) energy crops, assumed to be purpose-grown crops in support of an energy production facility, *e.g.*, switchgrass, high-yield wood fiber plantations.

The 15% federal Renewable Portfolio Standard (RPS) would dramatically increase wood consumption the United States. In the South, biomass export, biomass electricity, and advanced biofuels production would consume a total projected 308 million dry tons per year (Figure 5). The new biomass feedstocks defined by the Billion Ton Study (forest residues, urban residues, current farm residues, future energy crops, and future farm residues) would provide about 193 million dry tons of material . New biomass supplies appear inadequate to satisfy these incremental new demands of the renewable energy markets, with an annual gap in supply of 115 million dry tons. With no reductions in existing wood use, the demand nearly triples while the potential future supply doubles and the future gap in supply versus demand exceeds the current total demand for pulpwood in the Southeast.

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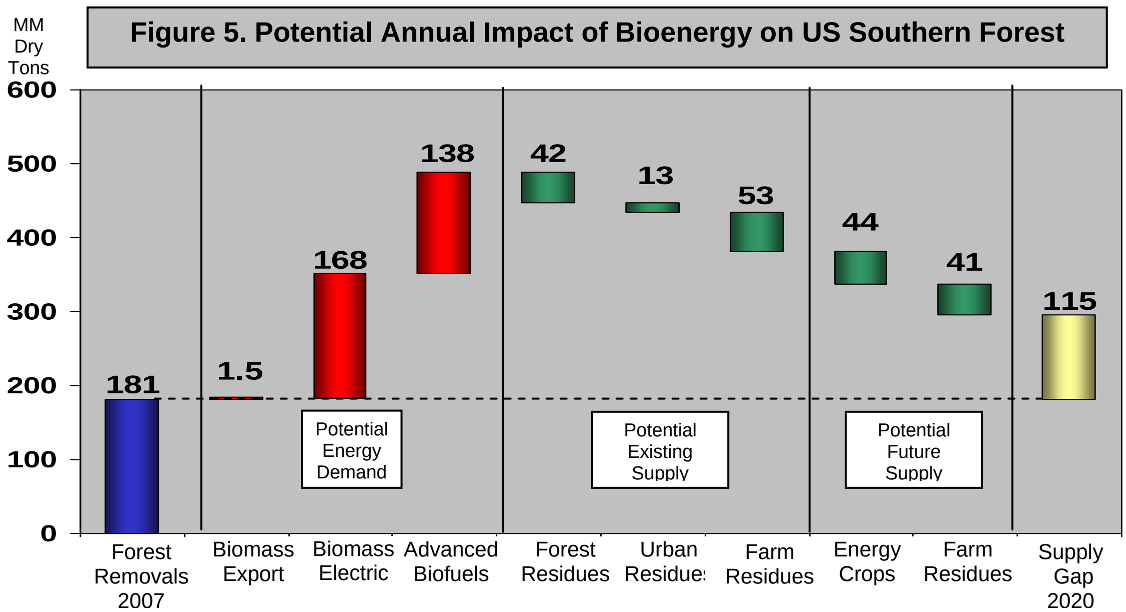
[20]21 billion gallons of Advanced Biofuel per the "Energy Independence and Security Act of 2007" times the fraction of the Southeastern forest's share of the total U.S. timber harvest.



This analysis demonstrates that bioenergy production would involve tradeoffs between various energy platforms and between the energy and wood products sector. With today's wood products industry, the energy-demand anticipated by recent policy initiatives could result in the doubling of harvests of pulpwood-sized roundwood. Because pulpwood supply, like the supply of most commodities, is price inelastic, this kind of production increase would entail substantial upward pressure on prices, especially over the short run. Economic fundamentals tell us that this would lead to adjustments across the wood using sector. We would anticipate that adjustments would involve the following: (1) contraction in the wood products sector, given that it is a mature industry with slim profit margins, (2) bioenergy firms having non-market competitive advantage in the market for biomass due to government subsidies (either subsidies for ethanol production or input requirements through RPS), and (3) expanded investment in timber growing that would play out over a longer time period.

Comatas and Shumacher's analysis indicates and Abt's analysis confirms that energy policies intent on expanding bioenergy production could have unintended consequences for existing industry. Given the magnitude of biomass demands and the availability of alternative sources (especially the limited logging residues) the bioenergy market would compete directly with forest products industry for raw material. The result would be a substantial upward pressure on prices and some localized scarcity of timber.

Sustainability and ecosystem services

The ecological impact of a cellulose based bioenergy sector in the South could be determined by (1) an expanded area of timber harvesting, (2) increased intensity of harvests, and/or (3) land use changes that shift either agricultural or forest land toward other biomass crops. Policy discussions have focused on using logging residuals (wood waste) as a feedstock for bioenergy operations. Our analysis of supply possibilities indicates that feedstock demands anticipated by policy initiatives would also require expanded harvesting. Both increasing utilization rates and expanding harvest areas raise concerns regarding the provision of various ecosystem services in the South.

From an ecological perspective, logging residuals are not wasted when left on the site. This residual material can provide wildlife habitat, slow the surface flow of water and reduce erosion potential, and over the years, as trees decompose, return nutrients to the soil and forming new organic layers. While it is not entirely clear how much wood is needed to adequately perform these functions, removing all the wood from a harvest site would harm some forest resource values (e.g., Hess and Zimmerman 2000).

Concerns regarding forest sustainability can be focused at either tract or regional levels. At the tract level, concerns mostly revolve around the amount of coarse woody debris that will remain on site after harvest and the effects on wildlife, water quality, and soil productivity.

Wildlife: Removal of coarse woody debris from harvest sites has been found to negatively impact breeding bird abundance, diversity and richness. For example, "neo-tropical migrants had fewer breeding territories on plots where downed coarse woody debris was removed."[21] Small mammals are also harmed by the removal of coarse woody debris from sites, including reduced reproduction and population levels for mice[22] and shrews.[23] These small mammals and other wildlife are essential for functioning forest systems. To maintain a diversity of wildlife species, harvested sites require standing and downed coarse woody debris while forests regenerate.

Water quality: Coarse woody debris promotes soil and slope stability, thereby decreasing the potential for erosion. Downed wood serves as a natural obstacle that captures, retains and stores eroding sediment.[24] Depending on the spatial arrangement of harvests, sites cleared of too much coarse woody debris could adversely affect the water quality of various stream courses.

Soil productivity / nutrients: The removal of all logging residuals could remove important sources of soil nutrients from the site. Scott and Dean (2006) find that removal of tops in addition to boles can lead to reduced biomass accumulation in the regenerated stand. In their study, productivity losses tended to be concentrated on infertile soils, but ameliorated through fertilization. Other studies (see reviews by Johnson and Curtis and Johnson et al.) confirm that productivity changes may be slight, and concentrated on low productivity sites, but readily treated using standard fertilizer applications. The addition of fertilizer or other mitigative measures needs to be accounted for in assessing the energy input to bioenergy operations (Scott and Dean found that bioenergy harvests are energy positive even with an accounting for fertilizer in their case study).

At the regional level, potential negative impacts include overharvesting; forest type conversion; more intensive management; and the loss of high conservation value forests for energy crops. But the greater concerns from an ecological standpoint are shifts in forest types from naturally regenerated to planted and intensively managed operations, including short rotation woody crops.

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[21] Lohr, Steven, Sidney Gauthreaux and John Kilgo. "Importance of Coarse Woody Debris to Avian Communities in Loblolly Pine Forests." Conservation Biology. 16(3): 767-777. 2002

[22] Loeb, S. "Responses of small mammals to coarse woody debris in a southeastern pine forest." Journal of Mammalogy. 80(2): 460-471. 1999. and Mengak, M and D. Guynn. "Small mammal microhabitat use of young loblolly pine regeneration areas." Forest Ecology and Management. 173(2003): 309-317. 2003.

[23] McCay, Timothy and Mark Komoroski. "Demographic responses of shrews to removal of coarse woody debris in a managed pine forest." Forest Ecology and Management. 189(2004): 387-395. 2004.

[24] Fuhrman, Nicholas. "An analysis of the ecology and public perception of coarse woody debris in Virginia." Thesis for Master of Science in Forestry. Virginia Polytechnic Institute and State University. 2004

Still another factor is the potential impact of biomass harvesting activities on forests as it relates to aesthetics, community relationships, and perceptions or expectations about the integrity of forest land as it appears on the landscape. Inherent in these concerns is the challenge of reconciling how such social or public values relate to private property decisions. While not subject to precise metrics, such considerations can become instrumental in political deliberations and can be more influential in crafting public policy than scientific debate. Such matters have been a significant part of state legislative discussions in the past, such as the controversies associated with chip mill establishment and expansion in Tennessee in the early 1990's. The extent to which these factors will affect federal and/or state policy is in part circumstantial. But, it is likely that these considerations will increase in significance where expanded biomass markets are also occurring in forested areas that are experiencing community and residential development.

Regional Water Supply: Increased reliance on wood biomass for energy production could increase water quality and water supply concerns compared to less intensive forest management, but wood biomass creates fewer impacts to water resources than annual row crops for energy production[25]. Assuming an increased prevalence of future droughts, water supply could be adversely affected by the siting and permitting of future biomass energy facilities (especially future ethanol plants[26]). Cellulosic biorefineries are estimated to use 9.5 gallons of water per gallon of ethanol.[27] The water demand can vary significantly by technology emphasized for energy production. These are issues that deserve additional research and careful consideration.

Regional Wildlife Impacts: Landscape and regional level implications of a bioenergy sector would likely depend on the spatial distribution of facilities and harvesting operations. Demand for wood biomass will be driven by the size of the energy generation facility (i.e. how much wood it uses) and proximity to other wood using facilities. If new facilities are drawn to areas with well-developed production infrastructure—e.g., where pulp mills are currently sited—then landscape-level impacts may be substantial as land management becomes more intensified. If they are drawn instead to areas with relatively large forest inventories and fewer competitors, then these impacts may be much less consequential.

In areas where production is concentrated, we might anticipate a shift toward intensive forest operations and away from other forest and agricultural uses. As a result, harvests could become more frequent and forest composition might become less complex. The ultimate impact of these changes on overall wildlife populations is uncertain. However, areas in the southern Coastal Plain, where current management intensity is highest have already experienced declines in key amphibian species. An expansion in edge habitat could also shift the distribution of bird species and perhaps away from threatened neotropical migrants. In all areas, increased harvest pressure might lead to conversion of some rare and important forest, for example long leaf pine and certain wetland types.

Implementing forestry Best Management Practices (BMPs) could provide a mechanism for mitigating many ecosystem service damages from increased timber production in the South. BMP's have been shown to effectively protect water quality during forestry operations. Shifts in harvesting techniques might signal a need to provide expanded breadth to BMP design. For example, wildlife BMPs could address 1) sufficient coarse woody debris on site; 2) retained snags

[25] National Research Council of the National Academies. "Water Implications of Biofuels Production in the Unites States." 2008. pg 58.
[26] See for example, article from Tampa Bay, Florida with water demands from new ethanol plant: http://www.economist.com/world/na/displaystory.cfm?story_id=10766882
[27] Water Implications of Biofuels Production in the U.S. National Research Council. 2007

and vertical structure; 3) protection of rare and declining forest types; and 4) restoration of key wildlife habitat elements. The uncertainty regarding on and off-site impacts clearly signals a need for expanded monitoring programs.

Conclusions

1. Absent wood-using bioenergy, the demand for the South's timber has declined from a peak in the late 1990s to levels comparable to the early 1990s. Pulpwood production fell by 15 percent between 1997 and 2006. At the same time, it appears that the timber-growing sector continued expansionary investment until at least 2000, further expanding timber supply. The price declines that accompanied these shifts indicate a decline in scarcity of timber over the last ten years and the price responsiveness of the sector. In a sense, new demands for bioenergy could provide a "replacement" for reduced demands from the pulp and paper sector. To put this in context, the difference between pulpwood production in 1997 and 2006 was roughly 0.9 billion cubic feet (Johnson et al. 2008) or about 10.8 million dry tons of biomass. Pulpwood prices (softwood) were 50 to 75 percent higher in the late 1990s, indicating that capturing this material for bioenergy would likely be associated with substantial price increases for the feedstock.

2. Timber growers in the South have long demonstrated responsiveness to expanded demands for timber. Increased production in the short run comes from expanding the area of harvest, while long run expansions require increased investment in production. Long run responses might be made substantial through the use of intensive plantation forestry or even intensive woody cropping technologies. Supply dynamics over the next two decades will critically depend on when this new investment commences and how long it takes for this adjustment in timber production capacity to ameliorate strong upward pressure on feedstock prices.

3. Land use changes and forest ownership changes raise uncertainty regarding the structure of supply, and especially, the location of future feedstock supplies.

4. The key determinants of bioenergy development in the South will be the emergence of technologies for commercial-scale production of transportation fuels from cellulosic biomass and the deployment of policies to encourage use of renewable energy. Several tax and subsidy approaches are encouraging innovation and investments in the bioenergy sector, but state-level Renewable Portfolio Standards may have the greatest sway over production in the short to medium run. Co-firing woody biomass with coal is a demonstrated technology that appears to be a preferred means of meeting RPS in the region. Because of the pricing structure of utilities, we expect that growth in this sector could have structural effects on timber markets in the South. RPS currently apply only in North Carolina and Texas but are being considered by other states.

5. Growth in the use of cellulosic bioenergy is likely to yield direct competition with existing wood products industry. The wood products industry is spatially heterogeneous so the extent to which competition has structural impacts depends on the location of new bioenergy facilities. The competitiveness of bioenergy at least in the short run depends on policy inducements to the sector and this defines potential for market distortion.

6. Liquid biofuels require extensive supplies of water in addition to biomass feedstocks. This may prove an important limiting factor regarding the development of a commercial scale bioenergy production, in the same way that water has organized and limited the

distribution of pulp and paper plants in the South. This coincidence of water demands may define yet another area of head-to-head competition between the two sectors and lead to a spatial concentration of harvesting.

7. Forests provide a multitude of services beyond fiber production. A substantial increase in harvesting or shift toward intensive management could have important implications for this natural infrastructure. Concerns focus largely on wildlife habitat and the protection of water quality in the region. For both, the extent of potential impacts depends on the eventual size of the sector and on the concentration of production. One focus of concern would be on intensifying management even further in the southeastern Coastal Plain where wetland forests are stressed and several amphibian species are already imperiled (Wear and Greis 2002). There is a high degree of uncertainty regarding thresholds of damage, suggesting the need for careful monitoring and designing management to minimize on and off site impacts.

References

Alavalapati, J.R.R., Hodges, A.W., Lal, P., Dwivedi, P., Rahmani, M., Kaufer, I., Matta, J.R., Susaeta, A. , Kukrety, S., Stevens, J.T.2008. Bioenergy Roadmap for Southern States, (SAFER Draft report).

Cobb, J.T. Jr., W. E. Elder. 2000. Cofiring urban waste with coal in stoker boiler, Proceedings of the bioenergy 2000, Moving Technology into the Marketplace, The Ninth Biennial Bioenergy Conference, 15-19.

Childs, B., and R. Bradley. 2007. Plants at the Pump: Biofuels, Climate Change, and Sustainability. World Resources Institute Report.

Coulson, B; Curry, G; Tchakerian, M; Gan, J; and Smith, C.T.. 2005. Utilization of plant biomass generated from Southern pine beetle outbreaks. http://forestscience.tamu.edu/Links/IEA_Bioenergy_Task_31/Workshops.htm

Dwivedi, P., Nesbit, T.S., Alavalapati, J.R.R., Lindner, A.S. (under review). A case study for assessing environment and economic suitability of cellulosic ethanol production from slash pine (Pinus elliottii) plantations in the United States

Energy Information Administration (EIA), 2008a. Retail sales of electricity to ultimate customers by end-use sector, by state. http://www.eia.doe.gov/cneaf/electricity/epm/table5_4_b.html. Cited 2 Oct 2008.

Energy Information Administration (EIA), 2008b. Refiner motor gasoline sales volumes. http://tonto.eia.doe.gov/dnav/pet/pet_cons_refmg_a_EPM0_VTR_mgalpd_m.htm. Cited 2 Oct 2008.

Fargione, J., J. Hill, D. Tilman, S. Polasky, and P. Hawthorne. 2008. Land clearing and biofuel carbon debt. Science 319(29): Pp1235-1238

Hill, J., E. Nelson, D. Tilman, S. Polasky, and D. Tiffany. 2006. Environmental, economic, and energetic costs and benefits of biodiesel and ethanol biofuels. Proceedings of the National Academy of Sciences of the United States of America.(PNAS) 103(30): 11206-11210.

Hughes, H. 2000. Biomass cofiring: economics, policy and opportunities, Biomass and Bioenergy 19(6):457- 465

Hunt, Suzanne. 2008. Biofuels, neither savior nor scam: the case for a selective strategy. World Policy Journal (spring): Pp9-17.

Mayfield, C. A., C.D. Foster, C.T. Smith, J. Gan, and S. Fox. 2008. Opportunities, barriers, and strategies for forest bioenergy and bio-based product development in the Southern United States. Biomass and Bioenergy 31: Pp631-637.

Milbrandt, A. , 2005. A Geographic Perspective on the Current Biomass Resource Availability in the United States, Technical Report, National Renewable Energy Laboratory, NREL/TP-560-39181, Dec. 2005.

Orts, W. J., K. M. Holtman, and J.N. Seiber. 2008. Agricultural chemistry and bioenergy. Journal of Agricultural and Food Chemistry 56:Pp3892-3899.

Perlack, R.D., L. L. Wright, A. F. Turhollow, R. L. Graham, B. J. Stokes, and D. C. Erbach. 2005. Biomass as feedstock for a bioenergy and bioproducts industry: the technical feasibility of a billion-ton annual supply. Oak Ridge National Laboratory, DOE/GO-102005-2135, 59p. http://feedstockreview.ornl.gov/pdf/billion_ton_vision.pdf

Reilly, J. and S. Paltsev. .2007. Biomass Energy and Competition for Land. Report series on the MIT Joint Program on the Science and Policy of Global Change. No 145.

Schmer, M.R., K.P. Vogel, R.B. Mitchell, and P.K. Perrin. 2008. Net energy of cellulosic ethanol from switchgrass. Proceedings of the National Academy of Sciences of the United States of America (PNAS) 105(2): Pp464-469

Searchinger, T., R. Heimlich, R.A. Houghton, F. Dong, A. Elobeid, J. Fabiosa, S. Tokgoz, D. Hayes, T. Yu. 2008. Use of U.S. croplands for biofuels increases greenhouse gases through emissions from land-use change. Science 319(29): Pp1238-1240

Susaeta, A., Alavalapati, J.R.R., Carter,D., (under review) Modeling Impacts of Bioenergy Markets on Nonindustrial Private Forest Management in the Southeastern United States.

Tillman, D.A. 2000. Biomass cofiring: the technology, the experience, the combustion consequences. Biomass and Bioenergy 19(6): 365-384

Timber Mart-South. 2008. South-wide average prices. Available online at http://www.tmartsouth. com/tmart/; last accessed October 23, 2008.

Tyler S. Nesbit, Janaki R.R. Alavalapati, Puneet Dwivedi, Marian V. Marinescu. (under review) Economics of ethanol production from slash pine (Pinus elliottii) plantations in the Southern United States

United States Department of Agriculture (USDA). 2008. Woody Biomass Utilization Strategy. FS-899. http://www.fs.fed.us/woodybiomass/strategy/documents/FS_WoodyBiomassStrategy.pdf

Wang, M., W. May, and H. Huo, 2007. Life-cycle energy and greenhouse gas emission impacts of different corn ethanol plant types, Environmental Research Letters Vol. 2, 024001, also available at http://www.iop.org/EJ/article/1748-9326/2/2/024001/erl7_2_024001.pdf?request-id=4b2ae20e-011c-48a2-b582-0900a1896e12.

Wear, D. N., Carter, D. R., Prestemon, J., 2007. The U.S. South’s timber sector in 2005. A prospective analysis of recent change. USDA Forest Service Southern Research Station, Asheville, NC.

Wear, D.N., and Greis, J.G. 2002. The Southern Forest Resource Assessment Summary Report. USDA Forest Service. 114 p.

World Bank. 2007. Biofuels: the promise and the risks. World Development 2008: Agriculture for Development. http://siteresources.worldbank.org/INTWDR2008/Resources/2795087-1191440805557/4249101-1191956789635/Brief_BiofuelPrmsRisk_web.pdf