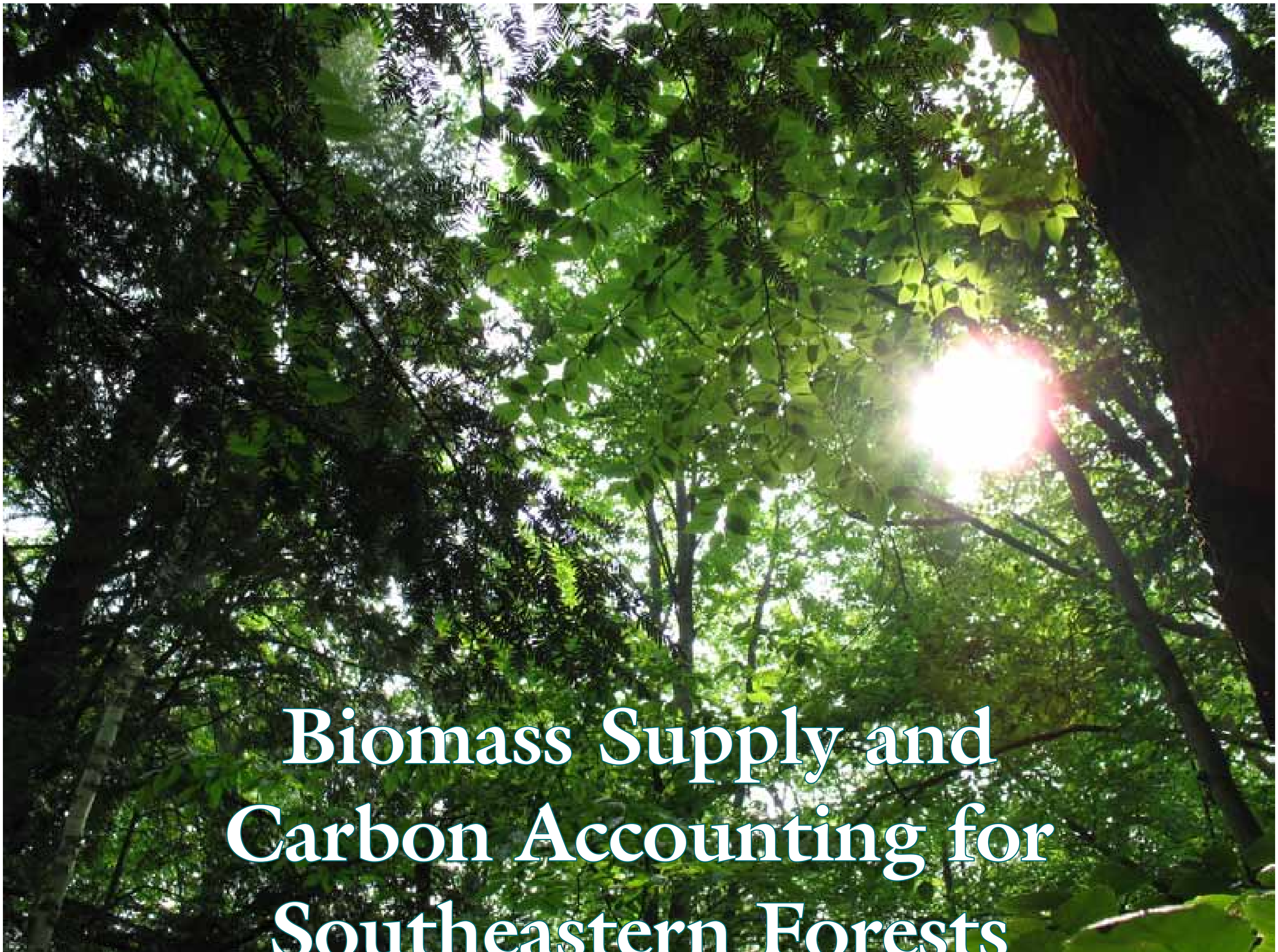

Biomass Supply and Carbon Accounting for Southeastern Forests

February 2012

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The views and conclusions contained in this report are those of the authors and should not be interpreted as representing the opinions or policies of the reviewers.

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Biomass Supply and Carbon Accounting for Southeastern Forests • February 2012

CONTENTS

EXECUTIVE SUMMARY

It is important to note that due to the emphasis in the Southeast on biomass electric power production, this study examines only the use of biomass for large-scale electric power generation (and electric-led combined heat and power, or CHP).

As climate change policy develops, forest biomass is consistently recognized as an alternative fuel with the potential to replace fossil fuels and mitigate the build-up of atmospheric carbon. In response to these issues, the southeastern United States has seen recent interest in significantly expanding the biomass energy sector, including building new power plants, co-firing with coal power in existing plants, pellet manufacture for export to Europe, and producing cellulosic ethanol. While some look to these developments and see promise, others look with great concern at pressures on the region's forests, implications for forest health and sustainable wood supply, and impacts on cumulative greenhouse gas emissions.

Until recently, governmental policies have almost unanimously reflected the opinion that energy from biomass is beneficial from a greenhouse gas (GHG) perspective. Biomass typically is included in energy portfolios as a renewable energy source in the same classification as wind and solar and is eligible for the same public incentives and subsidies. Starting in the early to mid 1990s, however, a number of studies looked more closely at the net GHG benefits of burning biomass and resulted in refined calculations of benefits depending on site factors, forest growth modeling, and timing of emissions and sequestration (Manomet, 2010). In the past few years, direct challenges to the accuracy of accounting approaches spurred a rethinking of carbon accounting for biomass (Searchinger, 2009).

As part of this emerging research, the US Environmental Protection Agency (EPA) is revisiting the premise that burning biomass for energy is carbon neutral in the context of the natural carbon cycle of the earth (EPA, 2011) and is considering regulating carbon emissions from biomass combustion. This study provides an example of how the "comparative" approach can be used for a specific region. It can be further evaluated by EPA to inform its criteria for an "accounting framework for biogenic CO_2 emissions from stationary sources."

KEY QUESTIONS

To address these complex issues as relevant to southeastern forests, this study seeks to address two key questions relevant to the biomass electric power sector in this region of the country:

- How much biomass (primarily wood) is available on a sustainable basis to source the expanding southeastern biomass electric power sector? And, what is the potential of public policy to create demands that exceed sustainable supply levels?
- How will the increased use of forest biomass for electric power generation in the Southeast affect atmospheric carbon over time, and how does biomass energy compare to several fossil fuel energy alternatives in terms of cumulative GHG emissions over time?

It is important to note that due to the emphasis in the Southeast on biomass electric power production, this study examines only the use of biomass for large-scale electric power generation (and electric-led combined heat and power, or CHP). Thermal energy pathways were not examined and due to their much higher efficiencies, these thermal technologies would have significantly shorter carbon payback periods and different overall impact on atmospheric carbon levels when compared to fossil fuel technologies (Manomet, 2010).

WOOD SUPPLY REVIEW

To assess the potential for sustainably harvested biomass (primarily wood) to fuel an expanded biomass energy sector in the Southeast, the study presents a literature review of several key biomass resource assessments conducted to date, examines the current and possible future energy policies that could drive the expansion of biomass energy development, and compares the supply with this potential demand. This portion of the study has three main parts:

1. assessment of the biomass resource literature for the seven-state region
2. examination of the energy policies in the seven-state region
3. comparison of the resource supply to the potential demand

The study does not present new primary fuel-supply analysis, but is based on a review of existing information. Main findings include the following points:

- Most studies conducted in the past six years quantify the gross or total amount of woody biomass material generated on an annual basis and do not quantify how much is already being used. Most of these studies focus on residues produced from other primary activities while evidence suggests nearly all the mill and urban wood residues are already used by existing markets.
- The evidence clearly suggests that any expanded biomass energy in the Southeast will come from harvested wood (either tops and limbs left behind from timber harvesting, whole trees, or pulpwood sourced from the main stem of a harvested tree).
- Whether logging slash, whole trees, or pulpwood will be used in the expansion of biomass energy in the Southeast will depend on the following:
  1. Which market the wood is going to (pellet mills need high-quality fiber from pulpwood while biomass plants are less particular about quality)
  2. How much demand increases within the pellet and power market sectors over time
  3. What happens with the pulp and paper industry in the southeast region in the future
- Prior to 2009, most fuel availability studies presented estimates of supply without any acknowledgment of the influence price has on the availability of these woody biomass resources. Since then, different studies have examined the economics using different indicators—making it difficult to compare results among the studies. For a clear assessment of the economics of woody biomass resources, the total delivered price paid by the receiving facilities is the best indicator to use.
- Various studies reviewed in this chapter used widely divergent assumptions regarding what percentage of the total amount of logging residue can be recovered from a harvested area. While the range observed in the literature was from roughly 50-100 percent, it should be noted that there is a difference between how much residue *can* be recovered and how much *should* be recovered when ecological factors are taken into account. While examining how much wood fuel could be generated if 100 percent of this material was recovered is useful for academic purposes, it is unrealistic to assume that such a high level can and should be realized. Ideally, studies would look at two critical issues when factoring the overall recovery rate—percentage of recovered residues on individual harvest operations and percentage of harvest operations where residues can be recovered.

It should be noted that there is a difference between how much [logging] residue *can* be recovered and how much *should* be recovered when ecological factors are taken into account.

EXECUTIVE SUMMARY *(cont'd)*

While some believe that biomass power demand will likely transition to procuring roundwood and displacing wood from the pulp and paper industry, it is actually more likely that growth in pellet markets—which demand higher fiber quality found in roundwood (not slash)—will be the market that most immediately displaces pulpwood.

- The availability of logging residues will largely depend on extraction methods. Where whole-tree harvesting systems can be used, these residues can be cost effectively accessed, however, the potential ecological effects of whole-tree logging need to be considered. Where mechanized cut-to-length and manual stem-only harvesting are used, these residues will not be easily accessible. Further analysis that determines how much whole-tree harvesting systems versus stem-only harvesting systems are used across this region would be very useful.
- Of all the states in the seven-state study region, North Carolina has had the most in-depth and sophisticated level of study of its biomass energy potential. In contrast, Alabama and Tennessee both had very little publicly available reports estimating biomass resources.
- Evidence suggests that there is likely enough wood to meet a 15 percent federal Renewable Energy Standard (RES) applied to each of the seven states (with the exception of Florida) when woody biomass sourced from local forests accounts for no more than 20 percent of the overall renewable electric generation target (or 3 percent of electricity supplied). It also appears, however, that adequate wood fuel resources are quite sensitive to the RES allocation. For example, if 30 percent of a 15 percent RES was allocated to forest biomass, it is likely there would not be enough wood fuel available within the region. A more aggressive RES standard for biomass leads to a higher likelihood of shortages and a greater probability of pulpwood displacement.
- Capacity to access and utilize residues is also a function of how much roundwood harvest occurs. More demand for roundwood generates more residues. The extent to which biomass power plants transition their wood procurement away from residues and toward roundwood is governed by the strength of the rest of the forest products industry. If the forest products industry strengthens as a result of greater lumber demand, it will increase its wood fiber consumption and as a result, biomass power plants would procure more residues at a lower cost and less pulpwood at a higher cost. If the forest products industry as a whole continues to contract, however, biomass power plants will likely transition toward procurement of chipped fuel from whole trees assuming they can absorb the higher cost associated with that transition.

While some believe that biomass power demand will likely transition to procuring roundwood and displacing wood from the pulp and paper industry, it is actually more likely that growth in pellet markets—which demand higher fiber quality found in roundwood (not slash)—will be the market that most immediately displaces pulpwood. Therefore, pellet mills and biomass power plants have somewhat complementary (almost symbiotic) procurement needs. Pellet production, especially the export market to Europe, will continue to play the wild card role in future wood fuel markets.

- The supply review performed as part of this study does not directly address potential ecological impacts of biomass energy sourcing. Additional analysis will be necessary to assess these impacts on other forest resources and values.
- The potential recovery rate for harvest residue is a key variable in determining the quantity of available wood fuel. Further research is needed to assess both the current achievable residue recovery rates and reasonable future recovery rates. Projected recovery rates need to consider woody biomass retention rates to meet wildlife and biodiversity, water quality, and soil productivity needs.

While this report has identified and probed some of the issues regarding the forest resource's capacity to produce more energy in the Southeast, there are numerous areas where key information is missing. More specific research is needed in the areas of: existing forest residue utilization, use of different harvesting systems, a comprehensive wood fiber assessment for the entire seven-state region, the price elasticity of demand between fuel chips and pulpwood, and the likely impacts of federal renewable energy standards on the economic incentives that drive project development.

ATMOSPHERIC CARBON ANALYSIS

To examine the atmospheric effects of biomass electric power generation in the Southeast, this study developed a new carbon accounting framework that integrates lifecycle carbon accounting with forest carbon accounting and utilizes forest growth, forest management practices, and supply data related to the specific situation in the Southeast. The framework is based on what we will call a "landscape-woodshed approach" where actual supply zones for specific facilities across the landscape are defined and aggregated as the basis for the study. Essentially, the study framework is designed to answer policy questions related to how atmospheric carbon would be affected if certain activities were promoted. It develops a "business-as-usual" baseline and then projects the atmospheric carbon effect of different future scenarios of creating electricity from woody biomass versus creating it from fossil fuels.

The framework [for this study] is based on what we will call a "landscape-woodshed approach" where actual supply zones for specific facilities across the landscape are defined and aggregated as the basis for the study.

Given the dynamics of the southeastern forestry sector, this study assumes that most of the trees modeled would eventually be harvested for pulp or other management objectives (such as to initiate the new stand under even-aged management) versus being left untouched if not harvested for biomass energy. The study excludes all public lands and 21 percent of private lands as not available for harvesting.

This is a more dynamic approach than was recommended in EPA's accounting framework for biogenic sources released in September 2011. Although, EPA acknowledged the "comparative" approach used in this study as a more comprehensive accounting method, it chose a "reference point" approach because of the perceived difficulties and challenges in applying a more dynamic approach to actual situations in the field.

EXECUTIVE SUMMARY *(cont'd)*

This study provides an example of how more dynamic accounting can be accomplished and should be considered by EPA in its carbon accounting deliberations. The results are consistent with other studies from other states or regions using similar analytical methods (Manomet, 2010 and McKechnie, 2011). Others have recently voiced opinions over which accounting methods are most appropriate. The SAF Task Force Report, Managing Forests because Carbon Matters: Integrating Energy, Products, and Land Management Policy (Malmsheimer et al., 2011), recommends a reference-point approach to establish forest biomass as carbon neutral. The European Environment Agency's Scientific Committee on Greenhouse Gas Accounting (European Environmental Agency, 2011) recently offered an opinion championing a comparative approach to fix a serious flaw in current GHG accounting.

Carbon Modeling Results

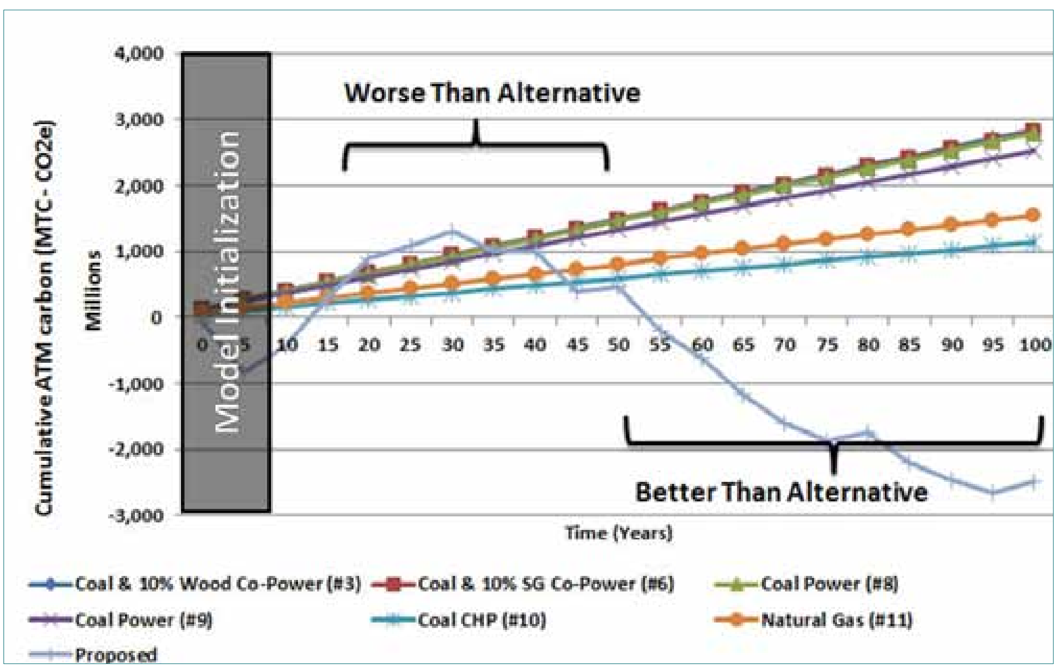
- The study modeled 22 new power plants as proposed to be developed over the next several years (1014 MW and 3.05 million tons of pellet production) added to an existing base of 17 power plants. The list of proposed plants is a snapshot compiled in May 2011 by the Southern Environmental Law Center. Additional large plants have since been proposed and are under development. As biomass demand increases with more facilities beyond the

Figure 22.

The study found that using southeastern forests for an expansion of electric power generation produced a significant long-term atmospheric benefit, but at short-term atmospheric cost.

The expanded biomass scenario creates a carbon debt that takes 35-50 years to recover before yielding ongoing carbon benefits relative to fossil fuels after this time period. (The initial apparent sequestration in the graph is a modeling artifact. It is a function of the simulation resolution and is due to the 5-year cycle with harvests mid-decade. This creates a 5-year growth period before harvest simulation.)

Figure 22. Cumulative atmospheric carbon balance over 100 years using coal and natural gas technologies to meet energy demand of proposed biomass facilities.



22 modeled, the ability of the forested landscape to provide biomass supply and store carbon may become more limited, particularly in localized areas with strong demand.

- The results indicated that the 17 existing biomass facilities were now generating and would continue to generate an improved atmospheric carbon benefit relative to fossil fuel technologies.
- The study found that using southeastern forests for the modeled expansion of power generation produced a significant long-term atmospheric benefit, but at short-term atmospheric cost. The expanded biomass scenario creates a carbon debt that takes 35-50 years to recover before yielding ongoing carbon benefits relative to fossil fuels after this time period (see Figure 22 on page 95). This outcome depends on the fossil fuel pathway used for comparison and assumes forests re-occupy the site through planting or natural regeneration, with no forest land conversion. This finding is consistent with other recent studies and naturally creates tension between climate scientists who assert that the next 20-30 years are a critical time for reducing carbon additions to the atmosphere and those who are more focused on long-term cumulative atmospheric carbon levels. This tension can only be resolved by well-informed energy and climate policy decisions.
- The efficiency of combustion technology was shown to be a critical factor influencing carbon emissions over time. The study used a mid-range value of 6,800 Bone Dry Tons (BDT) per megawatt hour per year. Using less-efficient combustion technology that requires more biomass per unit of power (e.g., using 8,000 BDT per megawatt hour per year) extends the payback period to 53 years. Using more efficient technologies would shorten this payback period. This study does not address biomass for thermal applications. While less common in the study area, strictly thermal applications or CHP applications are significantly more efficient and have much shorter carbon payback periods (in the range of 5-10 years in similar studies) than conventional combustion for base-load electrical generation that produces significant amounts of unused "waste" heat. The study also found that there is wide variability in carbon outcomes for different fuel types across different combustion systems.
- The use of logging residuals, when available from current harvests, leads to an improved carbon balance versus using standing roundwood because of the higher relative carbon storage of pulpwood versus residuals. The availability of harvest residue, however, is highly dependent on other parts of the wood products economy to generate sufficient demand for harvesting that creates residue material.
- The study did not model the use of dedicated energy crops for feedstock or crops that could be grown on fallow land and not jeopardize current sequestration and carbon stocks in existing forests. It attempted to analyze switchgrass based on information from a literature review, but this did not provide adequate or comparable information to what was available from our forest biomass modeling. Hence, a switchgrass analysis was dropped from the carbon modeling.

EXECUTIVE SUMMARY *(cont'd)*

One central issue to recognize is that [carbon] policy discussions include two competing perspectives—one long term and one short term—that will need to be assessed and weighed in the development of effective climate and energy policy.

DISCUSSION

The complex flux of forest-based carbon and the 35-50 year payback periods for the electric generation technologies modeled present both an intellectual and policy challenge. One central issue to recognize is that policy discussions include two competing perspectives—one long term and one short term—that will need to be assessed and weighed in the development of effective climate and energy policy. The long-term perspective focuses on the much lower amounts of atmopheric carbon that will eventually be realized if biomass is substituted for fossil fuels and the related beneficial effects for climate change and future generations. From this perspective, the 35-50 year payback period of biomass is less consequential. The short-term perspective, by contrast, believes near-term emission reductions are critical. This perspective is concerned with near-term "tipping points"—climate events that might be triggered by near-term increases in atmospheric carbon. From that perspective, the 35-50 year payback periods for biomass electric power are considered unacceptable climate and energy policy.

To further inform this discussion, it is useful to note that the carbon debt period shown in this study is consistent with other studies (Manomet, 2010, McKechnie, 2011) that have used life-cycle analysis, forest carbon accounting, and a business-as-usual baseline to compare biomass to other forms of energy production. As shown schematically in Figure 1 on the following page based on the Manomet study, there is an initial carbon "debt" relative to fossil fuels in the combustion of biomass for energy. Following a variable "payback" period, this debt is recovered and beyond that point biomass energy results in lower atmospheric carbon than fossil fuel alternatives.

The Manomet modeling produced a 42-year payback period for biomass- versus coal-generated electricity and the McKechnie modeling indicated 17-38 year payback periods for generating electricity with biomass instead of coal. Although these patterns are basically consistent, there are differences in debt periods, which are attributable to different forest types and harvest scenarios. In addition, our framework includes a more precise modeling of actual harvesting methods in real stands across the study region and linked to specific facilities.

Also there are significant differences between this study and the Manomet study in the time it takes to re-sequester all the emitted carbon and reach the point commonly called "carbon neutral." Our modeling indicates 53 years are required for this southeastern study region while the Manomet results for Massachusetts indicate more than 100 years are required.

Beyond the tension between this long- and short-term perspective, analyzing the climate implications of the biomass technologies modeled in this report is informed by several additional issues. First, recent climate studies indicate that whatever the ultimate peak in atmospheric carbon, it will take much longer than previously thought—hundreds or thousands of years—for the earth's systems to bring it back down to what are considered safe levels. This further complicates the understanding of how to address the short- versus long-term atmospheric carbon implications of biomass energy.

Second, it is possible to imagine future scenarios where technology leaps allow the retirement of such major sources of combustion as coal and biomass within 50 years. If realized, this would significantly shorten the payback period for biomass since facilities would be retired, biomass harvesting would stop, and re-sequestration would accelerate to shorten the payback periods. Conversely, it is possible to imagine land-use changes that would adversely affect the availability of biomass and negatively affect the payback periods. Concern over land-use change is well documented in the Southeast.

Third, it is necessary to fully consider any negative climate implications or events that could be triggered by the carbon debts created by the biomass scenarios. One should also consider whether these climate effects would eventually be triggered by continuation of the fossil fuel scenarios in the absence of biomass or other alternative fuels. Evaluating the cumulative costs and benefits to ecosystems and society of these factors over time is the task in front of policy makers in the southeastern region and at the national level.

Fourth, much of the carbon accounting debate for biomass centers on assumptions of baseline conditions. It is not uncommon to see studies that rely on generic "growth-to-removal" ratios as the key indicator of carbon accounting. The rationale is that as long as overall carbon stocks are being maintained in some specified area, then any biomass removal in that area is considered carbon neutral. This approach oversimplifies the accounting and can overlook very significant changes in forest carbon stock at the local level. They also do not accurately portray the foregone tons of new sequestration that would continue to accrue if those forests were not harvested for biomass.

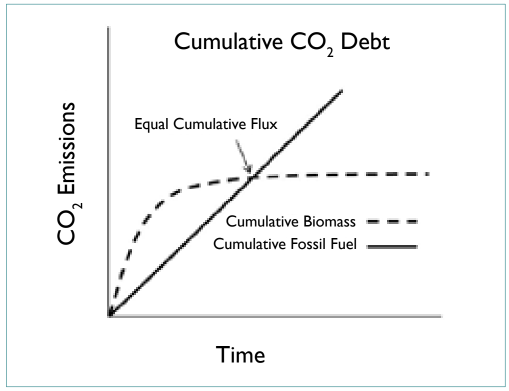


Figure 1.

Landscape-Scale Cumulative Carbon Debts and Dividends (Walker, 2012).

This study relies on a comparative approach that realistically estimates both the level of forest harvesting and the level of forest sequestration going forward in the absence of new biomass harvesting as a more accurate baseline approach. The approach used in this study can be applied to a region or an individual facility and should be useful for EPA as it develops regulations for GHG emissions.

INTRODUCTION

STUDY GOALS AND PURPOSE

The National Wildlife Federation (NWF) and Southern Environmental Law Center (SELC) contracted with the Biomass Energy Resource Center (BERC), in partnership with the Forest Guild and Spatial Informatics Group LLC, to provide an assessment of the greenhouse gas (GHG) impacts of an expansion of biomass electric power facilities in the southeastern United States. The study region is defined as a seven-state southeastern region including Virginia, North Carolina, South Carolina, Tennessee, Georgia, Alabama, and Florida. It is important to note that this study did not address thermal biomass energy applications, which have much higher efficiencies than electric power generation technologies and very different atmospheric carbon cycles. Nor did this study address the ecological impacts of current or increased biomass harvesting.

Until recently, governmental policies have almost unanimously reflected the opinion that energy from biomass is beneficial from a GHG perspective.

Energy supply and use is a national priority and a major focus of national, state, and local policy makers across the United States. The impacts of climate change, the need to increase energy efficiency, reduce reliance on foreign oil, and address related international security threats are some of the issues driving the expansion of new sources of domestic renewable energy and a new national energy policy and practice.

As climate change policy develops, forest biomass is consistently recognized as an alternative fuel with the potential to replace fossil fuels and mitigate the build up of atmospheric carbon. In response to these issues, the southeastern United States has seen recent interest in significantly expanding the biomass energy sector, including building new power plants, co-firing with coal power in existing plants, pellet manufacture for export to Europe, and cellulosic ethanol. Some of this increase in biomass utilization is driven by global demand and regulation and some by state-level renewable energy portfolios that require increased alternative energy production. To date, in the study region, North Carolina is the only state that has adopted a mandatory renewable energy portfolio standard, and Virginia has a voluntary standard. Additional state renewable portfolio standards or federal energy and climate change policies, however, will likely further increase the demand for biomass from southeast forests. According to Forisk Consulting, there are 149 announced projects in the southern United States that, in the unlikely event that they were all built, would consume more than 65 million green tons (Forisk Consulting, 2011). While some look to these developments and see promise, others look with great concern at pressures on the region's forests, implications for forest health and sustainable wood supply, and impacts on cumulative GHG emissions.

Until recently, governmental policies have almost unanimously reflected the opinion that energy from biomass is beneficial from a GHG perspective. Biomass typically is included in energy portfolios as a renewable energy source of the same classification as wind and solar and, when considered for electric power generation, is eligible for the same public incentives and subsidies. From an international perspective, policies have generally considered biomass energy to be a climate-friendly alternative to fossil fuels. In Europe for the past 10-15 years,

the International Energy Agency (IEA) has considered biomass energy to be close to carbon neutral (IEA, 2007 and 2009). The Intergovernmental Panel on Climate Change (IPCC), the primary international body focused on GHG emissions and mitigation strategies, also considers biomass energy to be an option for avoiding the GHG emissions from fossil fuels across all energy sectors (IPCC, 2000).

Starting in the early to mid 1990s, however, a number of studies looked more closely at the net GHG benefits of burning biomass and resulted in refined calculations of benefits depending on site factors, forest growth modeling, and timing of emissions and sequestration (Manomet, 2010). In the past few years, direct challenges to the accuracy of accounting approaches spurred a rethinking of carbon accounting for biomass (Searchinger, 2009).

As part of this emerging research, the US Environmental Protection Agency (EPA) is revisiting the premise that burning biomass for energy is carbon neutral in the context of the natural carbon cycle of the earth (EPA, 2011) and considering regulating carbon emissions from biomass combustion. In a 2010 rulemaking under the Clean Air Act—known as the Tailoring Rule—EPA planned to (and for a short while did) regulate carbon emissions from biomass plants as it did carbon emissions from fossil fuel burning facilities. EPA, however, also committed to studying the "carbon-neutrality" issue to determine whether the federal statute allowed carbon emissions from biomass combustion to be regulated differently than carbon emissions from the burning of fossil fuels. After extensive public and industry feedback on these new carbon emission rules as applied to biomass facilities, EPA proposed in March 2011 and finalized in July 2011 a different approach under which it instituted a three-year deferment of the regulation of biomass energy CO_2 emissions while it studied the underlying issue. During the study period, EPA said it would seek the advice of federal partners, states, a diverse group of expert scientists, and an independent scientific panel to help determine how these emissions should be treated under its air permitting program (EPA, 2011).

In September 2011, EPA released an "Accounting Framework for Biogenic CO_2 Emissions From Stationary Sources" to begin the discussion with experts and the public (EPA, 2011). EPA acknowledges several baselines that could be used in its framework, including the one used in this study, but selects a "reference-point" baseline that looks at the net change in carbon from a current reference point. Thus, if a region's stock of biomass contained more carbon after a specific point in time than the present, it would be assumed that biomass usage was not affecting atmospheric carbon. This southeastern study, by contrast, uses what EPA calls a "comparative" approach that identifies the net change that will occur in an alternative future, that is, how the carbon balance will be different if we use biomass as a source of energy versus using fossil fuels to produce that same amount of energy. The EPA framework also recognizes the carbon debt that could be incurred by land-use changes, but quantifies these emissions at a landscape scale and analyzes them on an annual basis. This southeastern study does not consider large-scale land-use change, but rather considers increased use of biomass energy harvested from forests on a sustainable basis. As this study points out, additional information is needed to determine how much additional forest biomass is available across the seven-state region to sustainably supply an expanded biomass energy sector without resulting in large-

Starting in the early to mid 1990s, however, a number of studies looked more closely at the net GHG benefits of burning biomass and resulted in refined calculations of benefits depending on site factors, forest growth modeling, and timing of emissions and sequestration.

INTRODUCTION *(cont'd)*

Overall, this literature review presents an overview of what is known about how much biomass resource is available in the region, what additional information is needed, and how closely matched current energy policy is with these available resources.

scale land-use change with related carbon and ecological effects. EPA's reasoning for selecting a less dynamic approach was the difficulty and challenges in accounting for these variables in actual situations. Others have recently voiced opinions over which accounting methods are most appropriate. The SAF Task Force report, Managing Forests because Carbon Matters: Integrating Energy, Products, and Land-Management Policy (Malmsheimer et al., 2011), recommends a reference-point approach to establish forest biomass as carbon neutral. The European Environment Agency's Scientific Committee on Greenhouse Gas Accounting (European Environment Agency, 2011) recently offered an opinion championing a comparative approach to fix a serious flaw in current GHG accounting.

This study provides an example of how the "comparative" approach can be used for a specific region. It can be further evaluated by EPA to inform its criteria for an "accounting framework for biogenic CO_2 emissions from stationary sources."

To address these complex issues as relevant to southeastern forests, this study seeks to address two key questions relevant to the biomass electric power sector in this region of the country:

1. How much biomass (primarily wood) is available on a sustainable basis to source the expanding southeastern biomass electric power sector, and, what is the potential of public policy to create demands that exceed sustainable supply levels?
2. How will the increased use of forest biomass for electric power generation in the Southeast effect atmospheric carbon over time and how does biomass energy compare to several fossil fuel energy alternatives in terms of cumulative GHG emissions over time?

It is important to note that this study examines only the use of biomass for large-scale electric power generation (and electric-led combined heat and power, or CHP). Thermal energy pathways were not examined, and due to their much higher efficiencies, these thermal technologies would have significantly shorter carbon payback periods and different overall impact on atmospheric carbon levels when compared to fossil fuel technologies (Manomet, 2010). It is also important to note that this study focuses solely on the carbon accounting of increased biomass use. There are significant ecological effects of increased removals of biomass from southeastern forests that must be evaluated and accounted for and were not within the scope of this study.

To examine fuel supply, the study conducts a literature review and critique of relevant and publicly available studies pertaining to the supply of biomass materials (primarily wood) in the seven-state region. It also examines current and future energy policies that could drive the expansion of biomass energy development and compares regional biomass supply with this potential demand. Overall, this literature review presents an overview of what is known about how much biomass resource is available in the region, what additional information is needed, and how closely matched current energy policy is with these available resources.

To examine the atmospheric effects of biomass electric power generation in the Southeast, the study develops a new carbon accounting framework that integrates life-cycle carbon accounting with forest carbon accounting and utilizes forest growth, harvest, and supply data related to the specific situation in the Southeast. The framework investigates specific landscape woodsheds associated with biomass facilities and develops business as usual baselines to compare to alternative future energy scenarios. This framework is designed to answer the following three questions:

1. What are the atmospheric carbon implications of operating the existing 17 biomass power plants in the study region versus not running them into the future and using fossil fuel instead?
2. What are the atmospheric carbon implications of operating the existing 17 biomass power plants as compared to operating these existing plants plus 22 new proposed biomass power plants? Answering this question includes a range of sensitivity analyses, including the impacts of varying the proportions of residuals versus pulpwood and natural forests versus plantations.
3. How does the atmospheric carbon balance vary when key parameters of the model are changed? The model and additional research were used to examine the sensitivity of six parameters to atmospheric carbon balance.

A NEW CARBON ACCOUNTING FRAMEWORK TAILORED TO SOUTHEAST FORESTS AND BIOMASS ENERGY

Comprehensive and specific accounting approaches are required to measure the effect of forest biomass energy systems on atmospheric carbon. Biomass systems are scientifically complex and their atmospheric carbon effects vary over time. Yet what makes them complex is also what can make them desirable for climate change mitigation—they are based on biogenic systems. A biogenic system such as a forest is part of the natural biological cycles of the planet. The carbon in a forest fluxes in and out of the atmosphere as trees grow and accumulate carbon and then die and release it. Fossil fuels, in comparison, are part of a geologic system. These fuels were stored in the earth millions of years ago and when extracted and burned for energy release additive carbon into the biogenic cycle. While the actual carbon molecules are identical, this additional carbon loading exceeds the sequestration capacity of existing forests and oceans. The resulting net increase in atmospheric carbon causes global warming and climate change.

Comprehensive and specific accounting approaches are required to measure the effect of forest biomass energy systems on atmospheric carbon.

The analysis of the atmospheric carbon impacts of biomass energy use would be straightforward and lead to the conclusion that biomass is preferable to fossil fuels in respect to reduction of GHG emissions except for three important facts. First, in most cases, the initial release of carbon into the atmosphere from burning biomass is higher than that of fossil fuels, as biomass is less energy dense than fossil fuels. This means that more biomass must be burned and more carbon released to get the same output of heat or electricity.

INTRODUCTION *(cont'd)*

Determining how biomass can contribute to a sound climate change policy hinges upon understanding this cycle of short-term costs and long-term benefits and weighing these costs and benefits relative to mitigating climate change over time.

Second, it takes time to re-sequester the carbon released from biomass combustion and to recover the foregone sequestration capacity lost when the biomass is harvested. Forests will respond differently to biomass harvests and this can result in varying and significant periods of time it takes to re-sequester the carbon. Depending on how the fuel is harvested and burned, CO_2 emissions from biomass can be re-sequestered in forests quickly or it may take many decades. Critical factors that influence the cumulative atmospheric carbon effects of burning biomass for energy include forest type, forest management, and how harvesting is distributed across the landscape and over time.

Third, the amount of CO_2 released per unit of energy produced varies significantly across different combustion technologies, with high-efficiency thermal technologies releasing far less carbon per unit of energy than electric power generation (Manomet, 2010). This is because much more usable energy value is available—as much as 70-80 percent in thermal applications—as compared to conventional combustion technologies.

Determining how biomass can contribute to a sound climate change policy hinges upon understanding this cycle of short-term costs and long-term benefits and weighing these costs and benefits relative to mitigating climate change over time. Specifically, effective energy and climate policy must consider both short-term carbon emissions and long-term atmospheric carbon accumulation and relate these factors to actual climate change tipping points and long-term mitigation goals.

These equations are complex and there is danger in blanket approaches or oversimplifications concerning the full life-cycle carbon effects of biomass energy. Research demonstrates that not all biomass energy can or should be considered a priori "carbon neutral." It is important to have a complete understanding of the three factors described above.

These concerns have led to refinements in biomass accounting protocols that now integrate life-cycle assessments and forest carbon accounting to produce a comprehensive picture of total GHG emissions over time. This study for the Southeast integrates these new accounting protocols with a "comparative" approach and a business-as-usual baseline to depict GHG emissions as a "debt-and-dividend" model as pioneered in a 2010 study, Biomass Sustainability and Carbon Policy, conducted for the Massachusetts Department of Energy Resources (Manomet, 2011). This report for Massachusetts described the flux of carbon at the forest-stand level when biomass is burned versus a fossil fuel as resulting in an initial period when biomass released more carbon into the atmosphere than an equivalent amount of fossil fuels. This difference (or "debt") gradually decreased as the harvested forest grew and sequestered carbon. If sufficient carbon is re-sequestered, the amount of carbon in the atmosphere becomes less than the fossil fuel alternative and dividends, or benefits, are accumulated over time. The study then used individual stand data to predict the results of running biomass facilities year after year, modeling carbon released into the atmosphere each year as more forest stands are harvested to supply biomass facilities.

Each year the cumulative amount of carbon in the atmosphere increased and was offset by the sequestration that occurred in the stands that were harvested and continue to grow. The cumulative debt rises until there is enough growth on the harvested stands already in the system to balance out the re-occurring debt from the yearly harvest and biomass emissions. At this point, the cumulative emissions for biomass stabilizes around an amount of carbon that, on average, has been permanently removed from the forest and will remain in the atmosphere as long as the biomass facilities are running and harvests continue. This curve can be plotted against the cumulative emissions from fossil fuel energy sources and technologies to provide a carbon flux analysis helpful for policy considerations.

The "debt/dividend" ratio and payback period will vary significantly across technology types and fossil fuel options with the shortest payback periods for biomass thermal energy and the longest for biomass electric power (Manomet, 2010). The most notable finding in the Massachusetts study was that biomass used to produce heat or heat-led CHP took only about 5-10 years to realize atmospheric carbon benefits relative to oil while biomass used to make electricity took approximately 42 years to achieve an atmospheric carbon benefit relative to coal. This is due to the significant difference in combustion efficiency between electrical-led versus thermal-led technologies.

The Manomet study was limited in scope due to available resources and time frame and reflected some peculiarities of a forestry sector that has few parallels in other states or regions, such as a lack of pulpwood markets for low-quality material, a reluctance of many landowners to conduct the sawtimber harvests that produce residues, and harvesting regimes that do not rely on clear cutting to establish new regeneration. Also, it modeled individual stands and averaged these to represent a broader landscape versus actually modeling multiple stands across a real landscape. For these reasons, there have been lingering questions as to whether the carbon flux profile would hold up under more comprehensive modeling in different regions and forest types and utilizing more accurate harvesting regimes.

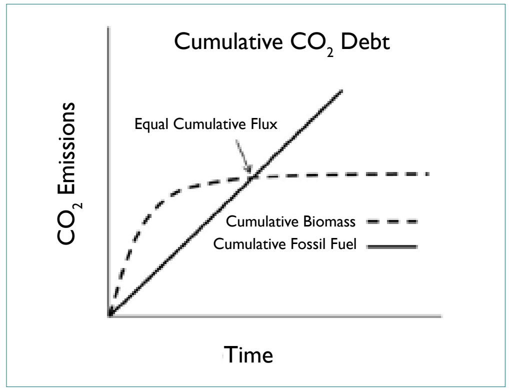


Figure 1.

Landscape-Scale Cumulative Carbon Debts and Dividends (Walker, 2012).

A related study in 2010 (McKechnie) also used an integrated approach of life-cycle analysis and forest carbon to analyze the effect of different biomass pathways compared to fossil fuels for forests in Ontario, Canada. It confirmed both the basic flux profile and significant payback periods for biomass electric power and cellulosic ethanol that were found in the Manomet study. Electrical generation using pellets in place of coal showed payback delays of 16-38 years and more than 100 years for ethanol produced from standing trees.

Enhanced modeling in this study allows a more accurate representation of GHG emissions over time and is specific to an actual forested landscape that is currently supporting 17 facilities and the expanded landscape that could be called upon to supply 22 proposed biomass facilities. The study uses life-cycle analysis and forest carbon modeling of actual forest stands across the landscape to produce a business-as-usual baseline and

INTRODUCTION *(cont'd)*

[This study] utilizes a dynamic model by predicting the role of repeated future harvests across the southeastern sourcing area for specific plants or "landscape woodsheds" as part of a business-as-usual scenario.

permit a comparison of generating energy from biomass to other ways of producing energy. The data is presented in a debt-and-benefit pattern to represent the carbon flux over time and facilitate policy development.

To further clarify several important characteristics of this study, the following issues are emphasized to facilitate comparisons to related work:

1. The GHG accounting framework used in this report represents a fresh and more realistic approach to estimate the landscape-level impacts of biomass energy expansion. In general, there are three ways to approach the modeling of GHG impacts of biomass energy:
   - Consider a *fixed landscape* and measure overall carbon stocks as an indicator of "biomass carbon neutrality" (EPA, 2011)
   - Conduct analysis at a *stand leve*l, multiplied upwards to estimate the landscape effect (Manomet, 2010)
   - *Consider a dynamic landscape and focus on "landscape woodsheds" to analyze the difference between emissions from the business-as-usual scenario and net changes in emissions from the increased use of biomass across different feedstock and technology pathways*

   Unlike other studies that rely on variations of the first two approaches, this report uses the third method (in italics above). That is, it utilizes a dynamic model by predicting the role of repeated future harvests across the southeastern sourcing area for specific plants or "landscape woodsheds" as part of a business-as-usual scenario. It is important to note that with respect to biomass energy, the term 'landscape' approach has come to mean several different things: most often a static balance-sheet approach to carbon stocks rather than the dynamic model used here.
2. Given the dynamics of the southeastern forestry sector, this study assumes that most of the trees modeled would eventually be harvested for pulp or other management objectives (such as to initiate the new stand under even-aged management) versus being left untouched if not harvested for biomass energy. The study excludes all public lands and 21 percent of private lands as not available for harvesting.
3. This study analyzes the harvest and carbon flows for specific woodsheds and biomass facilities. It predicts and models the harvest area and harvests from the specific forest types that would feed the biomass facilities.
4. This study includes a sensitivity analysis to evaluate several variables that can be manipulated through public policy to generate different carbon payback periods. These include:
   - **Mill residuals and urban tree waste.** Biomass power plants can use sawmill waste and urban tree waste as fuel (versus in-forest residues or pulpwood). How does the carbon payback change with varying proportions of this source of woody biomass versus in-forest residuals?
   - **In-forest residues versus main stem (pulpwood).** Biomass power plants can use in-forest residues (tops and limbs) or the main stems of standing trees. How does the carbon payback change as varying percentages of residues versus main stems are used for fuel?

- **Percentage of available residue allowed in harvest.** For ecological reasons, it may be necessary to limit the total amount of residues removed from the forest. How does the carbon payback change if residue harvest is limited by management guidelines?
- **Plantations versus natural forest stands.** Forest plantations are planted and manipulated much more intensively than natural stands and often have faster growth rates. The productivity of plantations versus natural stands was considered on a stand-level basis. Since the model used real sourcing areas for existing and proposed plants, however, it was not possible to adjust the supply upward for plantations when not enough plantation supply was available. Therefore, it was not possible to study the actual change in carbon payback periods for biomass sourced from plantations versus natural stands for the study region.
- **Efficiency of biomass combustion.** The efficiency of conversion of woody biomass to energy has a significant impact on the carbon payback period for electric power production. How does varying the amount of biomass needed to produce a MW of power change the carbon payback period?
- **Pellet export percentage.** Wood pellets are manufactured in the Southeast and are used domestically or exported to Europe to produce electric power. The study examines whether varying the level of pellet export significantly changes the carbon payback period.

The study presented here seeks to address these complex issues for the forest types, energy demands, harvesting regimes, and public policy environment specific to the defined seven-state forested region of the southeastern United States.

1. WOOD SUPPLY REVIEW

This literature review is focused on woody biomass resources and does not include other biomass materials such as farm manures, bio-solids, or agricultural residues.

1.1.0 INTRODUCTION

Over the past few years, there has been a flurry of biomass energy development activities in the southeastern United States—everything from announced cellulosic ethanol plants, to pellet mills exporting product to Europe, to new power plants and retrofitting coal power plants to co-fire using biomass fuel. While the promise of cellulosic ethanol commercialization and deployment has not yet come true, there is considerable progress underway in the pellet and power production fronts. A recent announcement released by a private consulting firm that tracks biomass energy development in the United States states that there are 81 proposed electric generation projects, 51 pellet plants, and 17 liquid-fuel production plants in the southern United States with a combined biomass feedstock demand of 65 million tons (Forisk Consulting, 2011). According to the same report, however, roughly half of these projects are deemed immediately unviable by the consultant for various reasons (unproven technology, financing, permitting, wood contracts, etc.). How many of the remaining projects will eventually get built is extremely difficult to predict.

At the same time, there have been dozens of different studies quantifying the various biomass resources. Some examine resources at the national level while others hone in on the regional and state levels. Many studies examine all biomass materials from bio-solids from waste-water treatment plants to animal manures from farms. Other studies focus exclusively on woody biomass. Some are public while others are conducted by consultants for private clients and are not publicly accessible. Some use transparent data, methods, and assumptions while others are more opaque. Some focus on quantifying the total generation of biomass materials while others try to identify the net amount available after all current demands are accounted for.

Considerable information is available at the state level about the supply of biomass resources, however, biomass materials like wood tend to constantly flow across state borders to feed the markets and are not confined to use by in-state markets. For this reason looking at the regional supply and potential demand for the resource is needed.

This chapter presents a literature review of several key biomass resource assessments conducted to date, examines the current and possible future energy policies that could drive the expansion of biomass energy development, and compares the supply with this potential demand.

1.2.0 SCOPE OF STUDY AND METHODS

1.2.1 Scope of Study

The scope of this section of the study has three main parts:

1. **Assessment of the biomass resource literature for the seven-state region.** This literature review is focused on woody biomass resources and does not include other biomass materials such as farm manures, bio-solids, or agricultural residues. It covers the studies and data that are publicly available and does not address the possibly vast amount of information that is not in the public domain.

More specifically, this assessment examined resource assessment studies that addressed the supply of urban wood residues (wood pallets, tree trimmings, leftover Christmas trees, etc.), wood residues from primary wood manufacturing (sawdust, chips, and bark from sawmills), wood residues for secondary wood manufacturing (scrap wood pieces, sawdust, and wood flour from furniture, cabinet, and flooring manufactures), logging residues from the harvest of traditional timber products (primarily the top and limb wood), wood residues thinned from pre-commercial harvests, and the possible harvest of pulpwood.[1]

2. **Examination of the energy policies in the seven-state region.** This examination includes the assessment of existing state Renewable Energy Portfolio Standards (RPS), the potential for a federal Renewable Fuel Standard (RFS), and a possible future federal Renewable Portfolio Standard.
3. **Comparison of the resource supply against the potential demand.** This comparison factors the woody biomass resource, the potential pellet export market, and the possibility for dedicated energy crops to bridge a potential gap between supply and demand.

Figure 2.

Seven-state study region in the southeastern United States.

1. WOOD SUPPLY REVIEW *(cont'd)*

This literature review limited the scope to those studies published since 2005 and that squarely addressed the quantity of biomass supply within at least a portion of the seven-state region.

1.2.2 Methods

For the literature review, all biomass studies in the seven-state region were gathered, this information was reviewed and assessed, the various pieces of information were woven together to paint a more comprehensive picture, and our findings and observations were reported.

The information gathered via the literature review was incomplete and further work to assess the full picture was necessary. BERC gathered more state-specific data from the USDA Forest Service's Forest Inventory Analysis (FIA) Program, and made basic calculations to better assess the forest resource potential against the possible future demands stemming from federal energy policies.

For the assessment of the RPS for the seven-state region, the study conducted the following tasks:

1. Review the seven-states' current energy policies, identify states with an existing RPS standard, and determine whether any such standards contain a "carve out" specifically calling for a percentage of the total portfolio to come from biomass, and more specifically, woody biomass.
2. Determine the current electrical demand profile in each of the seven states.
3. Explore new possible demand scenarios if a federal RPS and RFS were implemented.
4. Compare these scenarios against the resource amounts identified in the literature review.

1.3.0 ANNOTATED BIBLIOGRAPHY

The target of this literature review was on studies that quantify the amount of biomass resource potentially available to supply future growth of biomass energy in the seven-state region. It should be noted that there are dozens and dozens of studies published in the past 10 years that touch upon the issue of biomass fuel supply. Many of these studies, however, focus on different geographic regions, on different biomass resources, on the various ecological impacts, or on the economics of biomass fuel supply. This literature review limited the scope to those studies published since 2005 and that squarely addressed the quantity of biomass supply within at least a portion of the seven-state region. Studies that did not meet these criteria were excluded from the following summary.[2]

1.3.1 National Studies

1.3.1.1 The Billion-Ton Study

In 2005, a joint report between the US Department of Energy and the US Department of Agriculture was released that quantified the amount of biomass resources potentially available to expand the use of biomass energy in the United States (Perlack, 2005). This report, commonly referred to as the "Billion-Ton Study" provided national estimates of wood residues from timber and lumber production, crop residues, fuel wood thinned from forests to reduce fire hazards, and the role of dedicated energy crops. The report concluded that there was more than 368 million dry tons per year of woody biomass from the nation's forests and another 998 million dry tons of resources from agriculture. These estimates of supply are for total generation of supply

and do not account for current demands for this resource. These estimates also include key assumptions about implementing new practices in forestry and agriculture that will generate additional volumes not currently available (such as increasing forest thinning for fire-hazard reduction and planting of dedicated energy crops).

This study's major shortcomings were that it did not make any clear effort to delineate the amount of existing demand for these materials from existing industries. The reporting was given in totals for the nation and did not provide a state-by-state breakdown of the supply in the body of the report or appendices, and therefore cannot help directly in determining the likely supply for the seven-state region being examined as part of this report. Lastly, much of the data and methods used were not made transparent, therefore making it difficult to gauge the credibility of the information being reported.

In an effort to address many of the key shortcomings of the 2005 study, the authors have recently released a detailed update that has improved the spatial resolution of the information (county level data reported for all 50 states), provided price curves for the supply of various biomass resources (indicating the supply elasticity of the various biomass resources at different price points), improved upon the data and methods used, and provided more sophisticated modeling (including land-use change) to assess future supply under different scenarios. In August 2011, the updated Billion-Ton Study was released by the lead researchers at Oak Ridge National Laboratories.

The Billion-Ton 2011 Update assumed a logging-residues recovery rate of 70 percent, leaving the remaining 30 percent onsite. Perhaps one of the most relevant conclusions emerging from the 2011 update was the following statement:

"Over the estimated price range, quantities vary from about 33 million to 119 million dry tons currently to about 35 million to 129 million dry tons in 2030. Primary forest biomass (i.e., logging and fuel treatment operations and land clearing) is the single largest source of feedstock. The resource potential does not increase much over time given the standing inventory nature of the resource and how it is managed. Results also show that very little conventional pulpwood is available for bio-energy at prices below (about) $60 per dry ton." (Perlack, 2011)

These projections of wood biomass resources represent a very large decrease compared to the estimates given in the 2005 study (from 368 down to 129 million dry tons). The reasons for this decline given by the authors are the subtraction of biomass resources already in use and the recent decline in pulpwood and sawlog markets.

1.3.1.2 A Geographic Perspective on the Current Biomass Resource Availability in the United States

In December 2005, the National Renewable Energy Laboratory issued a report by lead author A. Milbrandt entitled, A Geographic Perspective on the Current Biomass Resource Availability in the United States. Unlike the 2005 Billion-Ton Study, Milbrandt provided state-by-state estimates for crop residues, wood residues, urban wastes, methane from manure and landfills, and dedicated energy crops. Milbrandt also provided detailed information on the data and methods used to create the estimates given in the report. To estimate the amount of mill residues and forest residues, the author used 2002 data from the FIA program's Timber Products Output (TPO) for logging residues from commercial harvest and pre-commercial thinning. Table 1 on the next page presents the estimates for forest residues presented in this report.

1. WOOD SUPPLY REVIEW *(cont'd)*

Table 1. Estimates for Forest Residues

STATE	DRY TONS OF FOREST RESIDUE FROM HARVESTING
Virginia	2,403,000
North Carolina	2,995,000
South Carolina	1,733,000
Georgia	3,556,000
Florida	1,778,000
Alabama	2,555,000
Tennessee	1,319,000
TOTAL	**16,339,000**

(Milbrandt, 2005)

These estimates are based on survey data on how much wood is harvested annually and calculations based on volume ratios between the amount of traditionally merchantable roundwood harvested and the amount of tops and limbs severed and left behind. With these types of estimates, it is important to note that the methodology used does not distinguish between the total amount generated and the amount that currently goes unused by existing markets. For this study, the estimates represent the total generated. It is also important to note that not all of this residue generated could be cost-effectively gathered. In practice, only whole-tree harvesting methods allow for cost-effective collection of the top and limb wood generally left behind with either manual or mechanized stem-only harvesting. Without good data on how much whole-tree versus stem-only harvesting occurs in the Southeast (or methods to predict changes in the ratio into the future), it is difficult to accurately estimate how much of this material is/will be truly available.

1.3.1.3 Availability and Sustainability of Wood Resources for Energy Generation in the United States

In this study commissioned by the American Forest & Paper Association, the authors focused on assessing the quantity of "wood resources for energy generation that exist independently of and in excess of those needed to manufacture other forest products and can be harvested without jeopardizing the long-term sustainability of US forests" (Mendell, 2010).

This study concluded that while there was a considerable decline in wood consumed by the forest products industry between 2005 and 2010, that by 2020 the industry would recover to previous levels of timber demand. The authors concluded, however, that the pulp and paper industry's consumption of raw wood would "remain flat and decrease."

This study built upon the Billion-Ton Study and made a good effort to isolate the portion of the total supply that is "readily available." While the original Billion-Ton Study concluded there is 368 million dry tons of woody biomass (revised to 129 million in 2011) from our forests available, this study concluded there are only 50 million dry tons (roughly 100 million green tons) readily available for energy use in the United States.

This study did not provide a state-by-state breakdown of the supply in the body of the report or appendices, and therefore cannot help directly in determining the likely supply for the seven-state region being examined as part of this report.

1.3.2 Regional Studies

1.3.2.1 Eastern Hardwood Forest Region Woody Biomass Energy Opportunity

In October 2007, the US Forest Service released a study entitled, Eastern Hardwood Forest Region Woody Biomass Opportunity. Prepared by Summit Ridge Investments, it focused on the market opportunities for utilizing woody biomass within a large eastern region (nearly every state east of the Rocky Mountains). It conducted some assessment of the resource building upon work conducted in the Billion-Ton Study and concluded that at the national level, of the 368 million dry tons annually, there are only 279 million dry tons available under current practices and activities. The additional 89 million dry tons would require new practices. It also concluded that within the Eastern Hardwood Region of the United States, there are approximately 190 million dry tons annually, however, 120 million dry tons are already used for existing markets. According to the author, the remaining 70 million dry tons available to supply additional biomass energy market expansion would represent a 50-percent increase over the current levels of wood consumption (Millard, 2007).

This study did not provide a state-by-state breakdown of the supply in the body of the report or appendices and therefore cannot help directly in determining the likely supply for the seven-state region being examined as part of this report.

1.3.2.2 Estimates of Biomass in Logging Residue and Standing Residual Inventory Following Tree-Harvest Activity on Timberland Acres in the Southern Region

The USDA Forest Service's Southern Research Station released in January, 2011 a report entitled, Estimates of Biomass in Logging Residue and Standing Residual Inventory Following Tree-harvest Activity on Timberland Acres in the Southern Region. The authors, Conner and Johnson, examined the amount of logging residues left by current harvesting and the standing trees left behind by harvesting that could be used for energy in a 13-state region of the southern United States. The authors examined all harvesting in the study area over the past 14 years and broke the harvesting into several categories—final harvest, commercial thinning, partial harvest, seed-tree/shelterwood, and Timber Stand Improvement (TSI). This study concluded there is the potential to recover an estimated 62.9 million green tons of harvest residues in their 13-state region annually.

Table 2 on the following page presents key information extracted from the Conner and Johnson study for the seven-state study region.

1. WOOD SUPPLY REVIEW *(cont'd)*

Table 2. Key Information Extracted from the Conner and Johnson Study for the Seven-State Region

	Final Harvest (Acres Harvested Annually)	Commercial Thinning (Acres Harvested Annually)	Partial Harvest (Acres Harvested Annually)	Shelter-wood (Acres Harvested Annually)	Timber Stand Improvement (Acres Harvested Annually)	Total (Acres Harvested Annually)	Logging Residue (Resulting Green Tons)
Virginia	133,600	55,100	117,900	2,600	10,400	319,600	4,863,222
North Carolina	227,500	101,800	87,100	2,100	10,600	429,200	5,936,953
South Carolina	149,800	200,000	63,900	13,200	13,000	439,800	4,773,409
Georgia	296,100	316,600	129,300	16,200	18,000	776,200	7,512,195
Florida	190,600	61,900	69,100	3,300	5,500	330,500	2,850,164
Alabama	366,400	275,200	164,600	14,900	15,600	836,700	7,951,820
Tennessee	56,600	4,400	161,500	3,900	1,200	227,600	2,905,345
TOTAL	**1,420,000**	**1,015,000**	**793,400**	**56,200**	**74,300**	**3,359,600**	**36,793,108**

Table 2 indicates that, according to the data and methods used by Conner and Johnson, there are more than 36 million green tons (or 18 million dry tons) of logging residues that could be used in the seven-state region, representing an average of 11.15 green tons per harvested acre. It is important to note that the authors chose to discount to the total amount of harvest residues calculated to account for a realistic recovery rate, using a 60 percent recovery rate for logging residues. It is unclear if this recovery rate is intended to be applied to all harvest operations where only 60 percent of the residue is gathered—factoring logistical and ecological reasons for not recovering more—or if this recovery rate applies to taking all residues from only 60 percent of the harvest operations. This is an important point because ideally, a study would look at both issues when factoring the overall recovery rate—percentage of recovered residues on individual harvest operations and percentage of harvest operations where residues can be recovered. In addition, the extent to which these harvest residues can be cost-effectively harvested depends largely on the type of harvesting system used by the loggers: Whole-tree harvesting can cost effectively extract this material whereas stem-only harvesting systems leave these materials scattered in the woods. To better understand how much top and limb wood residues from harvesting could effectively be accessed in the seven-state region, good information about how much whole-tree harvesting versus stem-only harvesting is needed. Unfortunately, other than general anecdotal information from loggers and foresters, this information was not found.

1.3.2.3 An Interactive Assessment of Biomass Demand and Availability in the Southeastern United States

In March of 2011, The Environmental Defense Fund and the Nicholas Institute for Environmental Policy Solutions at Duke University released a model and paper entitled, An Interactive Assessment of Biomass Demand and Availability in the Southeastern United States. The paper's authors, Galik and Abt, detailed the function and general results of the modeling work.

The model currently only holds data for three southeastern states—Georgia, South Carolina, and North Carolina. The model does not specifically quantify the amount of woody biomass potentially available, but rather explores the potential impact on the forest resource of hypothetical demand scenarios stemming from the adoption of a federal RES or a federal RFS. The model utilizes previous Sub Regional Timber Supply (SRTS) modeling work and feeds these data into an Excel spreadsheet where the impacts of various demand scenarios are compared to the biomass resource under different levels of resource constraints. The framework of the model explores a wide range of percentages of biomass contribution (or biomass "carve outs") toward a possible RES (1-10 percent) or RFS (0-150 percent).

On the whole, the modeling effort indicated that it was possible to meet the resource demands of all the different policy scenarios explored when whole-trees were an allowed resource. When the model parameters were confined to only harvest residues (tops and limbs left from traditional timber harvesting), however, there was insufficient resource to meet the energy policy targets of most scenarios for the three states.

One rather interesting observation the authors made concerned the potential for the displacement of traditional pulpwood by the increased demand and price paid by emerging biomass power generation markets. The authors suggested that "where the price of biomass increases, some existing users may essentially be priced out of the market," meaning those markets that are the most price sensitive with the least capability to pass along higher raw wood costs through the supply chain will have a harder time getting the resource. Galik and Abt state "we assume that the electric sector are not price sensitive... [and] as biomass prices increase, [existing forest products industry] are the first to be priced out" (Galik, 2011).

It is important to note that these assumptions are just that—assumptions. If a federal RES were implemented without set targets for biomass, solar, and wind, and biomass proved to be the most cost effective, then there is a chance demand for biomass could drive wood prices up to a point where biomass could outcompete pulpwood. There is little evidence, however, that such a reaction would take place. In fact, there is considerable evidence of the opposite. First, all RES implemented to date contain an alternative compliance payment that sets a cap on how high renewable energy credit prices can go. Second, the electric plants using biomass have historically been the most price-sensitive and constrained portion of the wood market (operating at 25 percent efficiency tends to limit how much they can afford to pay for wood fuel). Furthermore, the pulp and paper industry is not likely as price constrained as Galik and Abt suggest. The current market price paid for delivered fuel chips by power plants in the Southeast ranges between $22-$26 per green ton whereas the current price paid for delivered residual chips at pulpmills in the Southeast ranges from $32-$38 per green ton (North American Fiber Review, June 2011).[3]

1. WOOD SUPPLY REVIEW *(cont'd)*

Pulpmills also demand significantly higher quality chips that cost more to produce than the typical woodchip fuel used by power plants. In addition, the market value of the processed pulp is more than $500 per ton and the price of bulk paper is nearly $1,000 per ton. Even with an aggressive RES creating a strong incentive for biomass energy, it would be difficult to set a high-enough rate per MWh to price out pulp for the source wood while still making biomass energy even remotely price competitive with other sources of electric generation.

In certain circumstances, pulpwood can be sent to power plants—if a biomass power plant is very close to the harvest location and the nearest pulpmill is far away, pulpwood would likely be sent to the biomass plant as demand and prices rise for biomass fuel. If a harvest operation occurs 50 miles from the nearest biomass plant and 50 miles from the nearest pulpmill, however, under today's market prices the pulpwood will clearly go to the pulpmill.

1.3.2.4 Using Southern Interface Fuels for Bioenergy

In January 2011, the USDA Forest Service's Southern Research Station released a study examining the potential to use woody biomass sourced from within the Wildland Urban Interface (WUI) for biomass energy development. This study specifically examined the amount of wood residues from timber harvesting, unmerchantable wood from pre-commercial thinnings of timber stands, urban wood recycling, and exotic plant removals. It covers a 13-state region of the southern United States but did not present any new work regarding the amounts of woody biomass potentially available (Staudhammer, 2011).

1.3.3 State Studies

Due to the fact that the national and regional supply studies reviewed here thus far present little information specific to the seven-state region in question, our review now shifts its emphasis on gathering as much pertinent information on biomass supply in each state in an effort to compile these data for the whole seven-state area.

1.3.3.1 Virginia

Parhizkar and Smith (2008) conducted an assessment of wood residues in Virginia using GIS-based spatial analysis. Their analysis focused on the woody biomass residue generation from loggers, sawmills, secondary wood manufacturers, and landfills. The authors surveyed these sources and compiled the resulting data in a GIS application. They concluded that there is 8.1 million tons annually generated by wood products manufacturers in Virginia, but more than 90 percent of this material has existing markets. The assessment estimated that there was roughly 770,000 green tons of logging residues generated in 2003 and another 1.2 million green tons is disposed and sometimes diverted at landfills. Only eight percent of the total 10 million green tons was estimated to have inadequate markets (Parhizkar, 2008).

Another regional study that covered only the three states of Virginia, North Carolina, and South Carolina (Galik, Abt, and Wu, 2009) concluded there are 1.3 million dry tons (or 2.6 million green tons) of forest residues potentially available in Virginia (Galik, 2009). Galik et al. assumed a 50-percent recovery rate for logging residues.

Table 3. Estimates of Forest Residues in Virginia from Recent Published Studies

	Estimates of Forest Residues
Parhizkar and Smith (2008)	770,000 green tons
Galik, Abt, and Wu (2009)	2.6 million green tons
Conner and Johnson (2011)	4.8 million green tons

Table 3 above presents the wide range of estimates of forest residues in Virginia from recent published studies. When considering the 4.8 million green ton figure from the Conner and Johnson study, it is important to note that they quantified both logging residues from current harvesting activities and the amount of additional "standing residual inventory" left uncut by these harvests. Inclusion of this material is the prime reason for such high estimates.

1.3.3.2 North Carolina

Of all the states in the seven-state study region, North Carolina has had the most in-depth and sophisticated level of study of its biomass energy potential.

In the recently released (June 2011) La Capra report prepared for the North Carolina Energy Policy Council, the authors provided detailed estimates of biomass resources that could be used to help meet renewable energy targets in North Carolina (La Capra Associates, 2011). This analysis included estimates and projections for forest biomass, urban wood waste, and agriculture from within North Carolina and also select counties in Virginia and South Carolina (those covered within Duke Energy and Progressive Energy service territory). For this report, La Capra employed the services of Robert Abt, Christopher Galik, and Karen Abt who conducted detailed modeling using the SRTS model used in numerous other studies to forecast the supply of biomass fuel into the future under different sets of parameters.

Using this modeling method, the study team provided estimates of both the technical potential for supply and the practical potential for supply.[4] For the *technical* potential they estimated 6.73 million dry tons of logging residues and another 7.73 million dry tons of pulpwood (these recovery rates are generally considered to be on the high end of the range of what is viable).[5] It is important to note this estimate is not presented by the authors as the preferable scenario—its intent was to present an upper limit.

Accordingly, they provided a more realistic scenario of the resource capacity to expand biomass energy without the likelihood of adversely affecting the forest ecosystems and avoiding displacement of wood currently supplying the traditional forest products industry.[6] For the *practical* potential model runs, however, the supply was not modeled based on ecological constraints and layering in the demand levels of the traditional forest products industry. Instead, demand scenarios from expanded biomass energy markets were plugged into the model to see both their impact on the forest residue resource base and how much displacement of pulpwood would occur as a result after residue resources were exhausted. In other words the authors assumed that more demand for biomass would be met first by tapping into existing amounts of logging residues and then by taking some pulpwood away from current pulpwood markets with no net increase in pulpwood harvesting—rather than assuming that pulpwood for biomass fuel would result in a net increase in pulpwood harvesting.

1. WOOD SUPPLY REVIEW *(cont'd)*

Several scenarios were modeled and La Capra Associates concluded for the practical run that in the Duke /Progress service area in 2011, there are 11.6 million green tons (5.8 million dry tons) annually all from residues, or enough to support more than 1,000 MW of power plant capacity. As they modeled demand further into the future, the amount of pulpwood required by biomass energy plants increased (the threshold was estimated at about 12 million tons per year).

The La Capra report also concluded that for a biomass power plant to operate cost effectively given the capped incremental revenue of $35/MWh ($0.035 per kWh), the wood fuel cost for a 15-year period could not exceed $7.34 per green ton on a stumpage basis or $20.40 per green ton for delivered fuel. Yet evidence exists suggesting that power plants routinely pay more than $20 per green ton. Average second-quarter (2011) softwood chip prices paid by pulpmills in the southeastern United States was $35.50 per green ton. Given the incremental price cap and the current pulp value of wood fiber, there is little evidence to suggest a strong likelihood of displacement. If anything, the growth of the pellet market will have the greatest displacement potential of pulpwood because this growing market requires the fiber quality found in pulpwood and not in harvest residues.

It is important to note that many econometric studies, including the LaCapra study, present potential biomass fuel availability as a function of price and use the *stumpage* pricing paid for biomass and pulp as an indicator of the extent that biomass markets may displace pulp mill supply by turning to roundwood. While in some circumstances stumpage prices paid by the facilities directly to the landowner can dictate where the cut wood goes (and the logger is paid to merely cut and haul the wood to the given market), there are other situations where it is the *market* price paid at the wood processing facility's gate that dictates to which market cut wood flows. Such is the case with a timber sale where the logger pays the landowner stumpage and the logger decides where to take the wood based on where they can make the most profit (factoring transport costs and price paid at the gate).

Using a more conservative assumed harvest residue recovery rate of 50 percent, Galik, Abt, and Wu (2009) concluded there are only 2.8 million dry tons (5.6 million green tons) of forest residues available in North Carolina—less than half of the amount LaCapra estimates (LaCapra Associates, 2011). This lower harvest residue figure would dramatically reduce (from the LaCapra estimate of potential) the amount of electrical energy that could be generated from wood residues in North Carolina.

1.3.3.3 South Carolina

In April 2006, the South Carolina Energy Office released a report entitled, Biomass Energy Potential in South Carolina: A Conspectus of Relevant Information. This report was later revised and re-released in August 2008. This study examined the potential for direct combustion from solid biomass; methane production from various farm, municipal, and industrial wastes; and ethanol production from farm crops and residues. The study cites work previously conducted in the state that concluded there were 22 million green tons of woody biomass resources annually for biomass energy (Harris, 2004). Of these 22 million green tons, only 4.4 million were from logging residues.

Again, using the more up-to-date data, more sophisticated modeling, and a more conservative assumed rate of harvest residue recovery, Galik, Abt, and Wu concluded there are 1.8 million dry tons (3.6 million green tons) of forest residues potentially available in South Carolina.[7]

1.3.3.4 Georgia

The Georgia Forestry Commission's website reports its 2009 findings of an estimated 9.1 million dry tons more wood than what is being removed each year (Georgia Forestry Commission, 2009). A summary table presented on the commission's website provides nearly no background on the data source or methods used to come to this estimate, however, it does provide an itemized list of the various categories that add up to the 9.1 million dry tons. Figure 3 below is the summary table.

There is no clear indication where the information in the table comes from and what methods were used to make these estimates. It is also unclear whether these are intended to represent annual volumes. Furthermore, there is no clear indication whether the figures given in the "Inventory Amount" column are in units of green tons, dry tons, cubic feet, or some other unit of measure. It is assumed that the "Inventory Amount" column represents the total forest standing inventory and that the "Recovery Rate" column shows the annual rate of recovery. According to the Forestry Commission, there are 3.88 million green tons of logging residues generated annually in Georgia (assuming a 100 percent recovery rate).

Forestry Biomass Estimates for Georgia, General Statewide Assessments, 2009				
Resource		**Inventory Amount**	**Recovery Rate**	**Amount to Recover (oven dry ton basis)**
"Non-merchantable" biomass inventory in forests	Recovery during regeneration harvests	163,300,000	1.4%	2,286,200
"Non-merchantable" biomass inventory in forests	Recovery during thinnings	163,300,000	1.0%	1,633,000
Biomass from "pre-commercial" thinning of natural forest stands of pine and pine/hardwood		46,388,654	1.0%	463,887
Logging residues produced annually in forest management operations (excluding stumps)	From growing stock	1,940,250	100.0%	1,940,250
	From non-growing stock (included in non-merchantable biomass)	1,726,920	0.0%	0
Other annual timber removals resulting from land-use change	Estimate 75% recovery	1,834,625	75.0%	1,375,969
Mill residues produced annually		7,305,000	0.0%	0
Recoverable urban wood waste annually		1,436,823	100.0%	1,436,823
			Total	**9,136,128**

Figure 3.

Summary table of estimated dry tons of wood removed from Georgia each year.

1. WOOD SUPPLY REVIEW *(cont'd)*

Florida's forest resources lay mostly in the northern part of the state whereas many of the other states in the region have fairly even geographic distribution of their forest resources.

1.3.3.5 Florida

In March 2010, the University of Florida released a report entitled, Woody Biomass for Electricity Generation in Florida: Bioeconomic Impacts under a Proposed Renewable Portfolio Standard (RPS) Mandate. In the report the authors, Rossi, Carter, and Abt, explore the resource supply response to the possibility of mandatory RPS of 20 percent renewables by the year 2021. The authors model various scenarios, including the use of merchantable timber, urban wood waste, and logging residues.

In this study, the authors assume that a large percentage of the 20 percent renewable energy target will come from woody biomass energy based on the assertion that other renewables like wind and solar have both technological and cost constraints. Rossi et al. found that logging residues and urban wood waste resources in Florida "do not comprise a significant amount of aggregate supply of woody biomass required under a 20 percent RPS." Furthermore, they concluded that a significant portion of the demand presented by a 20 percent RPS would need to be met using merchantable timber. It is important to note that the authors have assumed that 100 percent of the RPS would be met from woody biomass energy and nothing would come from other renewable sources.

The authors state in the executive summary, "It is widely assumed that Florida's abundant wood resources would be relied upon in order to meet much of the RPS-imposed demands for electricity, given that factors such as technological constraints and cost considerations will combine to limit the amount of renewable energy that will come from solar, wind, and other sources of renewable energy" (Rossi, 2010). There is no clear evidence to support or dispute this statement by Rossi, et al. Certainly, representatives from the wind, solar, and biogas energy industries would dispute the validity of this assertion.

Anecdotally, it is important to keep in mind that Florida's forest resources lay mostly in the northern part of the state whereas many of the other states in the region have fairly even geographic distribution of their forest resources.

1.3.3.6 Alabama

In June 2009, the Alabama Forestry commission released a report entitled, Woody Biomass Energy Opportunities in Alabama. Only very basic information regarding potential supply and demand of biomass resources is provided in this report.

1.3.3.7 Tennessee

No further studies were found for Tennessee.

1.4.0 APPLES-TO-APPLES BIOMASS RESOURCE ASSESSMENT OF SEVEN-STATE REGION

1.4.1 Summary of Wood Residues

Due to the fact that each of the studies detailed on the previous pages looked at different groups of biomass resources, quantified the resource with and without also quantifying the current use, used different data sources and different methodologies, and studied different geographic regions, there is no rational way to weave together all the various disparate studies and bits of information. To supplement the bits and pieces of state-specific information from all the various sources and studies presented earlier, the Table 4 below was created by BERC to present a consistent set of information for the biomass resource for each of the seven states.[8] It presents information assembled into fact sheets for numerous southern states by the SUN Grant initiative (Southern Forest Research Partnership, 2011).

The information presented in Table 4 is useful, yet must be put into the proper context. While nearly 50 million dry tons of annual woody biomass generation in the seven-state region may seem like a lot of biomass, without knowing how much of that amount is already being used by existing markets, it is somewhat meaningless. A large majority of recent fuel supply studies have concluded that nearly all primary and secondary wood processing mill residue (chips, sawdust, wood flour, shavings, and bark) and urban wood waste are already being utilized by wide-ranging existing markets. Pulpmills have long utilized paper-grade chips from sawmills. Many wood processors also use their own wood residues to fuel their kiln drying of lumber. Also some sawmills in the region have added pellet mills to their operations, thereby further utilizing their own residues. Agricultural markets have long been a steady outlet for sawdust and shavings for animal bedding. The landscaping and horti-

A large majority of recent fuel supply studies have concluded that nearly all primary and secondary wood processing mill residue (chips, sawdust, wood flour, shavings, and bark) and urban wood waste are already being utilized by wide-ranging existing markets.

Table 4. Biomass Resource for Each of the Seven States

	Urban Wood (DT/yr)	Mill Residues (DT/yr)	Harvest Residue (DT/yr)	Total (DT/yr)
Virginia	813,000	800,926	1,700,000	3,313,926
North Carolina	833,000	5,000,000	2,300,000	8,133,000
South Carolina	467,000	2,400,000	1,600,000	4,467,000
Georgia	1,440,000	8,000,000	3,500,000	12,940,000
Florida	4,600,000	2,600,000	1,300,000	8,500,000
Alabama	100,000	6,800,000	2,700,000	9,600,000
Tennessee	614,000	577,000	760,000	1,951,000
TOTAL	**8,867,000**	**26,177,926**	**13,860,000**	**48,904,926**

1. WOOD SUPPLY REVIEW *(cont'd)*

To give an accurate picture of whether the broader forest resource could support the potential increased demand from biomass energy beyond just the use of harvest residues, a detailed analysis for the seven-state region is needed.

culture markets have been a consistent outlet for bark (especially softwood species). Composting operations also rely on wood residues as a feedstock for mixing with sewage sludge, farm manure, and food wastes. Composite wood products industries such as particle board and oriented-strand board use various wood residues. Food flavoring industries like meat smoking use wood wastes as well. Unfortunately, little data exist on the exact consumption from each of these markets for the seven-state region.

Of the three categories listed in Table 4, it can be generally assumed that harvest residues (13.86 million dry tons per year for the seven states) are the untapped resource. It should be noted again, however, that to cost effectively extract these residues, whole-tree harvesting systems are essential. Therefore, the portion of the harvest residues generated by mechanical cut-to-length and manual stem-only harvesting are not accessible. None of the studies assessed in the literature review directly mention this point.

1.4.2 Summary of Forest Capacity for Harvested Wood Fuel Beyond "Residues"

While harvest residues have a certain potential to supply future growth of biomass energy in the southeastern United States, there is a limit to how far these resources can go in light of the gradual decline in timber harvesting over the past decade. Less wood cut for traditional markets equals fewer residues for biomass energy. At some point, biomass markets may prefer a more reliable source of fuel coming from wood harvested for the purpose of energy. Few of the studies examined in the literature review explore this potential.

To give an accurate picture of whether the broader forest resource could support the potential increased demand from biomass energy beyond just the use of harvest residues, a detailed analysis for the seven-state region is needed. This was not feasible given the scope, timeline, and budget of this study. The following section provides an extremely basic and overly simplified assessment of the forest resource to supply wood above and beyond the current demands. *This information is not intended to present accurate estimations; these numbers are for conversational purposes only.* It should be noted that forests are extremely complex and dynamic systems and any effort to quantify their inventory, growth, and capacity to supply additional amounts of wood fuel should be interpreted as being an oversimplification with a wide margin of error.

In an effort to examine the potential capacity for expanded use of forest biomass evenly across the seven-state region using consistent data and methods that are "apples to apples," we used an approach that would provide a quick-glimpse sense of the resource capacity. This approach makes numerous assumptions and takes several basic steps:

1. Assume that all the urban wood, and primary and secondary wood residues all have existing markets and that any new market growth for biomass energy will be met with harvested wood
2. Identify the total forestland land area in the seven-state region
3. Identify the total amount of standing forest inventory on that forestland footprint
4. Identify the amount of net annual growth[9] of new wood

Table 5. USDA Forest Service FIA Data for Seven-State Region[10,11]

	Forestland Area (Acres)	Total Inventory[12] (GT)	Net Growth (GT)	Removals (GT)	Net (GT)
Virginia	15,900,000	1,009,323,529	30,117,647	19,173,235	**10,944,412**
North Carolina	18,600,000	1,052,941,176	43,000,000	33,764,706	**9,235,294**
South Carolina	12,900,000	632,352,941	35,294,118	19,676,471	**15,617,647**
Georgia	24,800,000	1,102,941,176	58,823,529	47,058,824	**11,764,706**
Florida	16,900,000	567,647,059	23,823,529	17,617,647	**6,205,882**
Alabama	22,900,000	835,294,118	49,676,471	37,705,882	**11,970,588**
Tennessee	13,800,000	761,764,706	24,941,176	17,647,059	**7,294,118**
TOTAL	**125,800,000**	**5,962,264,706**	**265,676,471**	**192,643,824**	**73,032,647**

5. Identify and subtract the rate of annual removals for the seven-state region
6. Calculate the net supply of annual growth beyond current removals
7. Make more assumptions regarding the percentage of this amount that is available

Table 5 above presents this approach in detail for each state.

Knowing how much the forests are growing and what level of harvest can be sustained over time gives a basic picture of wood fuel availability and the viability of woody biomass energy.

When forests are examined from a broad perspective, wood inventory can be compared to money invested in a bank account that earns interest annually. The total annual growth of trees in a forest is analogous to the interest earned on capital invested. A wise financial investor strives to spend only the annual interest earned each year and not dip into the principal. Forests are the same: Sound forest management policy within a state or region limits harvesting to within a range that approximates the amount of annual growth so that growth-to-removal ratios are maintained in rough equilibrium.

For the purpose of this assessment, the net annual growth of new amounts of wood was chosen as the indicator of how much wood the forests of these states can provide on a sustained-yield basis.

On the surface, the data presented above indicates that there is more than 73 million green tons of annual growth of new wood beyond the current demands for timber products in the seven-state region. It should be noted, however, that the FIA data above is focused on the growing stock portion of the total forest inventory and does not account for the amount of top and limb wood. Thus, in theory there is more than that. While 73 million green tons of new wood annually seems like a lot, the reality is that it is dramatically less. Forest management and periodic harvesting occurs only on a portion of the forested footprint and therefore, physical, ecological, and social constraints on the land area

1. WOOD SUPPLY REVIEW *(cont'd)*

on which supply is estimated must be taken into account. Normally, detailed modeling would be conducted to factor such constraints (steep slopes, stream buffers, critical wildlife habitat, landowner attitudes, parcel size, etc.), but as that was beyond the scope of this study, we applied an overly simplistic assumption of 50 percent reduction to crudely account for these factors. This yields an estimated 36.5 million green tons of un-utilized annual growth beyond current market demands. This assumes that all of this annual growth beyond current removals would be available exclusively to energy markets and would not simultaneously feed other traditional timber markets. This is an unlikely scenario even though some forecasts indicate that no other wood market is poised to grow as significantly in the future as biomass energy.

If all this wood was utilized for biomass energy in the future, it translates to an average increase in harvesting of 0.58 green tons per acre per year (spread over the total forested footprint of each state). This 36.5 million green ton amount will be revisited in greater detail in Section 1.5.2. Again, it must be emphasized that these numbers are for discussion purposes only and do not represent any estimates (implied or otherwise) by the authors of how much wood could actually be available in the future.

1.5.0 ASSESSMENT OF THE RENEWABLE PORTFOLIO STANDARDS

This section explores both the existing state RPS (mandatory and voluntary) and the potential for a federal Renewable Energy Standard.

1.5.1 Current State Renewable Energy Portfolio Standards

At the present time, only three of the seven states in this study area have Renewable Energy Standards—Virginia, North Carolina, and Florida. Of these three states, only North Carolina's standard is mandatory—Virginia and Florida's are voluntary. The following section provides further details of these current standards.

1.5.1.1 Virginia

Virginia enacted a *voluntary* renewable energy portfolio goal in 2007 and further legislation was passed in 2009 to expand the goal—encouraging investor-owned utilities to purchase a percentage of the power sold from renewable energy sources. In addition, the Commonwealth of Virginia offers a performance incentive to participating utilities in the form of an increased rate of return (profit) for each "RPS Goal" attained. Electricity must be generated or purchased in Virginia or in the interconnection area of the regional transmission entity.

The voluntary targets set out in the standard are defined as percentages of the amount of electricity sold in 2007 (the "base year"), minus the average annual percentage of power supplied from nuclear generators between 2004 and 2006.

Table 6. Virginia RPS Schedule

	Target
RPS Goal I:	4% of base year sales in 2010
RPS Goal II	Average of 4% of base year sales in 2011 through 2015, and 7% of base year sales in 2016
RPS Goal III	Average of 7% of base year sales in 2017 through 2021, and 12% of base year sales in 2022
RPS Goal IV	Average of 12% of base year sales in 2023 and 2024, and 15% of base year sales in 2025

Investor-owned electric utilities can gain approval to participate in the voluntary RPS program from the Virginia State Corporation Commission, the entity that oversees utilities, if the utility demonstrates that it has a reasonable expectation of achieving the 12 percent target in 2022.

Eligible energy resources include solar, wind, geothermal, hydropower, wave, tidal, and biomass[13] energy.

- Onshore wind and solar power receive a double credit toward RPS goals
- Offshore wind receives triple credit toward RPS goals
- Existing renewable energy generators like older hydro are eligible for RPS compliance

1.5.1.2 North Carolina

North Carolina's Renewable Energy and Energy Efficiency Portfolio Standard (REEPS) was established by Senate Bill 3 in August 2007. It requires all investor-owned utilities in the state to supply 12.5 percent of 2020 retail electricity sales (in North Carolina) from eligible energy resources by 2021. Municipal utilities and electric cooperatives must meet a target of 10 percent renewables by 2018.

Under this standard, eligible energy resources include solar-electric, solar-thermal, wind, small hydropower, ocean wave energy, biomass, landfill gas, CHP using waste heat from renewables, hydrogen derived from renewables, and electricity-demand reduction. Up to 25 percent of the requirement may be met through energy efficiency technologies, including CHP systems powered by non-renewable fuels. After 2021, up to 40 percent of the standard may be met through energy efficiency.

The overall target for renewable energy includes technology-specific targets “carve outs” or “set asides” of 0.2 percent solar by 2018, 0.2 percent energy recovery from swine waste by 2018, and 900,000 megawatt-hours (MWh) of electricity derived from poultry waste by 2014.

The compliance schedule for investor-owned utilities appears in Table 7 on the following page.[14]

1. WOOD SUPPLY REVIEW *(cont'd)*

A typical biomass power generation plant of 20 MW per hour capacity would require approximately 250,000 green tons of woody biomass fuel annually.

Table 7. Compliance Schedule for Investor-Owned Utilities

Year	Percent Target from Eligible Renewable Energy	"Set Asides" for Specific Sources
2010	0.02%	From solar
2012	3%	0.07% from solar 0.07% from swine waste 170,000 MWh from poultry waste
2013	3%	0.07% from solar 0.07% from swine waste 700,000 MWh from poultry waste
2014	3%	0.07% from solar 0.07% from swine waste 900,000 MWh from poultry waste
2015	6%	0.14% from solar 0.14% from swine waste 900,000 MWh from poultry waste
2018	10%	0.20% from solar 0.20% from swine waste 900,000 MWh from poultry waste
2021	12.5%	including 0.20% from solar + 0.20% from swine waste + 900,000 MWh from poultry waste

Utilities must demonstrate compliance by purchasing renewable energy credits (RECs) and a REC is equivalent to 1 MWh of electricity derived from a renewable energy source, or an equivalent amount of thermal energy in the case of CHP and solar water heating, or 1 MWh of electricity avoided through an efficiency measure. Any excess RECs accumulated by a utility may be applied to the next year's compliance target. Utilities may use unbundled RECs from out-of-state renewable energy facilities to meet up to 25 percent of the portfolio standard.

It is important to note that there is no minimum target for biomass energy from woody biomass sources, however, the commission will provide triple credit for every one REC generated by the first 20 MW of a biomass facility located at a "cleanfields renewable energy demonstration park." A typical biomass power generation plant of 20 MW per hour capacity would require approximately 250,000 green tons of woody biomass fuel annually.

1.5.1.3 Florida

Florida does not have a state-wide RES, however, in November 1999, JEA, a municipal utility servicing the greater Jacksonville area, signed a Memorandum of Understanding with the Sierra Club and the American Lung Association of Florida to formalize the municipal utility's commitment to generate at least 7.5 percent of its electric capacity from green energy sources by 2015. Eligible renewable energy resources include solar, biomass, biogas (methane from landfills and sewage treatment plants), and wind as well as specific efficiency projects.

1.5.1.4 Discussion of Current State Standards

It is unclear how much, if any, new woody biomass electric generation capacity will occur as a direct result of the voluntary standards set in Florida or Virginia. Although North Carolina has a mandatory standard for specific levels of renewable energy by specific dates, it is also unclear how much, if any, new biomass power generation capacity will be developed as a direct result of this policy. Certainly the triple credit applied to the first 20 MW of capacity of a biomass plant in North Carolina is a strong incentive that could result in an additional demand of 250,000 green tons of woody biomass. Given the emphasis on both poultry and swine manure in the North Carolina standard, it is also feasible that the first 20 MW that receives this triple REC credit could be fired with farm manure rather than wood.

Without any "set aside" specifically for woody biomass, it is unclear how much, if any, biomass energy development will result directly from these policies. Will other renewables (wind, solar, hydro, swine or poultry manure) be developed first and meet the targets? Will a REC price go high enough to make electric generation using woody biomass more attractive to developers? Any effort to predict the cause-and-effect relationship between a voluntary or mandatory RPS and the resulting demand from forests is highly speculative at best.

Yet, numerous new biomass power plants are being proposed as well as proposals to convert existing coal plants to burn biomass fuel. Given the flurry of biomass project proposals prior to the existence of any meaningful RPS, the question becomes what is currently driving this development activity? There are several modest incentives available to biomass power plants that improve the economics beyond market wholesale rates for sale of electricity. Interviews with plant managers and experts in the field of electric power regulation and development and further analyses of federal subsidies indicate that, generally, the most important current federal incentive is the Production Tax Credit, or PTC ($10 per MWh). Select states in the United States such as Massachusetts have adopted aggressive RPS policies that have created RECs ranging $0.02-$0.03 per kWh. While the value of a REC is higher, the price varies significantly in the marketplace with the cycling of RPS requirements, emergence of new technologies, construction of new renewable energy facilities, the state of the economy, and demand for electric power. While less valuable at only $10/MWh, the federal PTC is a more stable source of income for biomass plants over time.

Without, a clear economic incentive like a REC or the PTC for the biomass plants, many utilities in the Southeast proposing to build biomass power plants would likely be forced to request a rate increase from the state regulatory agencies to absorb the higher costs of electricity from biomass. While dozens of proposals to build biomass power plants are under development, historically only a very small percentage of the total proposals ever get built.

While dozens of proposals to build biomass power plants are under development, historically only a very small percentage of the total proposals ever get built.

1. WOOD SUPPLY REVIEW *(cont'd)*

1.5.2 Potential for a National Renewable Energy Portfolio Standard

For the purpose of this study, we were asked to explore the impact of the passage of a federal RES. There are currently 36 states in the United States with some form of a RES and these state standards vary widely in their target percentages and due dates. The resulting patchwork of energy policies is often confusing and chaotic. In 2010, a group of six US senators introduced a bill to adopt a federal RES. While the bill did not pass, it has raised the energy sector's awareness of what impact such a federal standard could have on our energy portfolio in the future.

At this time, it is unclear that if a federal standard were passed, what the overall target percentage, the target dates, and what specific "set asides" for various allowable technologies would be. Furthermore, the extent that each state had to meet these federal targets on their own or whether the targets could be met when averaged for all 50 states, is also unknown. There is no reliable way to predict how much woody biomass demand would be created by the passage of a federal RES at this time.

Given the numerous variables and uncertainties mentioned, and in an effort to explore the impacts of a federal RES, we must make some assumptions to form a series of "what if" scenarios. Let's start with the assumption that a federal RES is applied evenly to each state and requires compliance at the state level, not averaged up to the national level. Let's also assume that the federal RES contains a specific "set aside" for biomass and more specifically for woody biomass as a subset to the biomass category.

Table 8. US Energy Information Administration State Energy Data System – 2009 Electric Consumption

	Total Electric Consumption (trillions of Btu)
Virginia	370.1
North Carolina	435.6
South Carolina	260.7
Georgia	446.2
Florida	766.8
Alabama	282.7
Tennessee	322.9
TOTAL	**2,885.0**

Tables 9 and 10 below examine a scenario where a federal 15 percent RES target is achieved using forest biomass as fuel to achieve 20 percent of that overall target (or 3 percent of the total).

Table 9. Calculated Target Amount of Energy to Be Met from Biomass				
	RPS Target	**Resulting Amount of Energy (trillions of Btu)**	**Assumed % for Biomass**	**Amount of Energy from Biomass (trillions of Btu)**
Virginia	15%	55.5	20%	11.1
North Carolina	15%	65.3	20%	13.1
South Carolina	15%	39.1	20%	7.8
Georgia	15%	66.9	20%	13.4
Florida	15%	115.0	20%	23.0
Alabama	15%	42.4	20%	8.5
Tennessee	15%	48.4	20%	9.7
TOTAL		**432.8**		**86.6**

Assuming 1.22 green tons per MWh (e). Numbers may not sum due to rounding.

Table 10. Comparison of Wood Needed to Meet Target and Estimated Supply			
	50% of Annual Growth beyond Annual Harvest (as calculated in Section 1.4.2)	**Green Tons Required to Meet 15% RES with 20% from Forest Biomass**	**Difference**
Virginia	5,472,206	3,977,237	1,494,969
North Carolina	4,617,647	4,681,125	-63,478
South Carolina	7,808,824	2,801,583	5,007,241
Georgia	5,882,353	4,795,037	1,087,316
Florida	3,102,941	8,240,328	-5,137,387
Alabama	5,985,294	3,038,003	2,947,291
Tennessee	3,647,059	3,470,008	177,051
TOTAL	36,516,324	**31,003,322**	5,513,003

Numbers may not sum due to rounding.

1. WOOD SUPPLY REVIEW *(cont'd)*

In Section 1.4.2, we calculated (in grossly oversimplified terms) that there is 36.5 million green tons of forest capacity (new annual forest growth in excess of current removals), and that to meet a 15 percent federal RES with 20 percent coming from woody biomass, approximately 31 million green tons would be needed. While the total number of tons needed to meet the federal RES targets are less than the calculated values representing the total potential resource, on the state level, both Florida and North Carolina indicate a greater demand for woody biomass than the supply from forest biomass.

Sensitivity analysis indicates that when the percentage of the 15 percent RES that comes from woody biomass is decreased from 20 percent to 15 percent, all states with the exception of Florida have sufficient resources to meet the potential demand from that policy scenario. In Florida, even when the percentage is further lowered to 10 percent coming from woody biomass, our calculations indicate insufficient woody biomass resources. Florida has considerable forest resources in the northern half of the state, but this result is due to the extremely high levels of electric demand in Florida—nearly twice that of the second largest consumer of electricity, Georgia.

Table 11. Comparison of Wood Needed to Meet Target and Estimated Supply

	50% of Annual Growth beyond Annual Harvest (as calculated in Section 1.4.2)	Green Tons Required to Meet 15% RES with 30% from Forest Biomass	Difference
Virginia	5,472,206	5,965,856	-493,650
North Carolina	4,617,647	7,021,688	-2,404,041
South Carolina	7,808,824	4,202,374	3,606,450
Georgia	5,882,353	7,192,556	-1,310,203
Florida	3,102,941	12,360,492	-9,257,551
Alabama	5,985,294	4,557,005	1,428,289
Tennessee	3,647,059	5,205,012	-1,557,953
TOTAL	**36,516,324**	**46,504,982**	**-9,988,658**

Numbers may not sum due to rounding.

On the contrary, when the sensitivity analysis increased the amount of woody biomass contributing toward a 15 percent RES from 20 to 30 percent, more than 46 million green tons were required—leaving nearly all the states (with the exception of South Carolina and Alabama) in a woody biomass deficit. Table 11 on the previous page illustrates the conceptual outcome of meeting a 15 percent federal RES with 30 percent coming from forest biomass in the seven-state region. Under this scenario only South Carolina and Alabama have sufficient in-state forest resources to meet the state-level energy targets.

It is important to note that our calculations do not closely match with the model runs conducted by Galik and Abt because our crude calculations were static projections of growth over removals and do not directly account for any displacement of pulpwood. The Galik and Abt study used sophisticated models that accounted for some levels of displacement of pulpwood harvest over time. Any number of further scenarios of different federal RES levels and different woody biomass targets could be calculated but that did not fall within the scope of this study.

Because there was no significant shortfall in woody biomass resources when a 15 percent RES using 20 percent woody biomass was examined, no further assessment of agricultural residues or dedicated energy crops were required to meet this particular demand scenario. With a 30 percent biomass component for a 15 percent RES, however, there is a significant woody biomass deficit in most of the study states. Furthermore, if the pellet market continues to expand and increases its wood sourcing throughout the southeastern United States, further constraints would be placed on the resource and a 15 percent RES using 20 percent woody biomass may have difficulty achieving its target. Of course, conversely, if several pulpmills in the southeastern region shut down in the near future, that would free up a considerable amount of wood supply.

1. WOOD SUPPLY REVIEW *(cont'd)*

1.6.0 REVIEW OF FEDERAL RENEWABLE FUELS STANDARD

The federal Renewable Fuels Standard (RFS) program was established under the Energy Policy Act of 2005 and created the first renewable fuel mandate of 7.5 billion gallons of renewable fuel to be blended into gasoline by 2012. A proposed update is under development by EPA with a planned release date of November 2011 for the compliance year of 2013. The proposed targets call for a mixture of cellulosic biofuel, biomass-based diesel, advanced biofuel, and renewable fuel adding up to 15.2 billion gallons of equivalent ethanol (EPA, 2011).

A federal RFS could have an impact on woody biomass resources and several years ago there was strong evidence to suggest that cellulosic ethanol would have a major role in the future demand put on our forests. Over the past two or three years, however, less emphasis has been given to this use due to the continuing struggles to achieve commercialized production of cellulosic ethanol from wood fibers.

"One potential driver of demand for forest biomass is the federal Renewable Fuel Standard (RFS), which sets minimum standards for how much gasoline and diesel fuel must be produced from renewable sources each year. However, the initial announced targets have been steadily lowered in the face of shortfalls in production, and it is expected that energy crops and other sources would likely be preferred over wood feedstock for producing cellulosic ethanol. Our model runs therefore assume no forest biomass is used to meet RFS-driven demand for biofuels." (La Capra Associates, 2011)

Because all evidence clearly suggests that woody biomass will play only a minor role in producing liquid transportation fuels and that the technology development to implement such a demand is still years away, we have chosen to not explore the implications further.

For hypothetical purposes, let's explore the 36.5 million green tons of conceptual annual supply from the seven-state region, and see how many gallons of cellulosic ethanol that would yield (assuming fully commercialized plants get built). Assuming a yield of 40 gallons per green ton, nearly 1.5 billion gallons of ethanol could be produced, leaving no further woody biomass resources for expansion of any other market. This would account for slightly less than 10 percent of the national RFS2 target (US Department of Energy EERE, 2011). If cellulosic ethanol production expands in the near future, however, there is a high likelihood that agricultural biomass resources will contribute significantly.

1.7.0 CONCLUSIONS

Most studies conducted in the past six years quantify the gross or total amount of woody biomass material generated on an annual basis and do not quantify how much is already being used. Most of these studies focus on residues produced from other primary activities while evidence suggests nearly all the mill and urban wood residues are already used by existing markets.

The evidence clearly suggests that any expanded biomass energy in the Southeast will come from harvested wood (either tops and limbs left behind from timber harvesting, whole trees, or pulpwood sourced from the main stem of a harvested tree).

Whether logging slash, whole trees, or pulpwood will be used by the expansion of biomass energy in the future will depend on:

1. Which market the wood is going to (pellet mills need high-quality fiber from pulpwood and biomass plants are less particular about quality)
2. How much demand increases within the pellet and power market sectors over time
3. What happens with the pulp and paper industry in the southeast region in the future

Prior to 2009, most fuel availability studies presented estimates of supply without any acknowledgment of the influence price has on the availability of these woody biomass resources. Since then, most fuel supply assessments have begun factoring the economics and present the availability of the resources as supply curves depicting the amount of material potentially available at different price points. The original and the updated Billion-Ton Study are good examples.

It is important to point out that different studies have examined the economics using different indicators, making it difficult to compare results among the studies. Several studies only examined stumpage prices paid to landowners (Galik and Abt, 2011) for wood fuel, which do not reflect any cost to harvest, extract, process, or transport, while other studies focus exclusively on prices paid "roadside" for yarded wood (Perlack and Stokes, 2011), which do not reflect the cost of transport. Still other studies focus on the total delivered prices paid at processing facilities (mills or power plants). For a clear assessment of the economics of woody biomass resources, the total delivered price paid by the receiving facilities is the best indicator to use.

Various studies reviewed in this chapter used widely divergent assumptions regarding what percentage of the total amount of logging residue can be recovered from a harvested area. The range observed in the studies was from roughly 50-100 percent. While examining how much wood fuel could be generated if 100 percent of this material was recovered may be useful for academic purposes, it is unrealistic to assume that such a high level can and should be realized. It is unclear from these studies whether these recovery rates are intended to be applied to all harvest operations where only a percentage of the residue is gathered—factoring logistical and ecological reasons for not recovering more—or if this recovery rate applies to taking all residues from only a percentage of the harvest operations. This is an important point because ideally, a study would look at both issues when factoring the overall recovery rate—percentage of recovered residues on individual harvest operations and percentage of harvest operations where residues can be recovered.

The evidence clearly suggests that any expanded biomass energy in the Southeast will come from harvested wood (either tops and limbs left behind from timber harvesting, whole trees, or pulpwood sourced from the main stem of a harvested tree).

1. WOOD SUPPLY REVIEW *(cont'd)*

Logging residue amounts will be difficult to access due to extraction methods. Where whole-tree harvesting systems can be used, these residues can be cost-effectively accessed. Where mechanized cut-to-length and manual stem-only harvesting are used, these residues will not be easily accessible. Further analysis determining how much whole-tree harvesting systems versus stem-only-harvesting systems are used in this region would be very useful.

Of all the states in the seven-state study region, North Carolina has had the most in-depth and sophisticated level of study of its biomass energy potential. Alabama and Tennessee both had very little publicly available reports estimating biomass resources.

Our quick supply estimate exercise suggests that there is likely enough wood supply in the forests to meet a 15 percent federal RES standard applied to each of the seven states (with the exception of Florida and possibly North Carolina) when woody biomass sourced from local forests accounts for no more than 20 percent of the overall renewable generation target. It also appears, however, that adequate wood resources are quite sensitive to the RES allocation; if for example 30 percent of a 15 percent RES was allocated to forest biomass, it is likely there would not be enough wood fuel available within the region. A more aggressive RES standard for biomass leads to a higher likelihood of shortages and a greater probability of pulpwood displacement.

Capacity to access and utilize residues is also a function of how much roundwood harvest occurs. More demand for roundwood generates more residues. The extent to which biomass power plants transition their wood procurement away from residues and toward roundwood is governed by the strength of the rest of the forest products industry. If the forest products industry strengthens as a result of greater lumber demand, they will increase their wood fiber consumption and as a result, biomass power plants will be able to procure more residues at a lower cost and less pulpwood at a higher cost. If the forest products industry as a whole continues to contract, however, biomass power plants will likely transition toward procurement of chipped fuel from whole-trees *assuming* they can absorb the higher cost associated with that transition. Future demand for roundwood from the pulp and pellet industries will play a role in determining how much roundwood is used for power production.

While some believe that biomass power demand will likely transition to procuring roundwood and displacing wood from the pulp and paper industry, it is actually more likely that growth in pellet markets—which demand higher fiber quality found in roundwood (not slash)—will be the market that most immediately displaces pulpwood. In fact, this is already happening. If pellet demand continues to grow and results in increased levels of roundwood harvest, then pellets may well determine the future level of harvest residue available for the power plants to utilize.

Therefore, pellet mills and biomass power plants have somewhat complementary (almost symbiotic) procurement needs. Pellet production, especially the export market to Europe, will continue to play the wildcard role.

While this report has identified and probed some of the issues regarding the forest resource's capacity to produce more energy in the Southeast, there are numerous areas where key information is missing. More specific research is needed in the areas of: existing forest residue utilization, use of different harvesting systems, a comprehensive wood fiber assessment for the entire seven state region, the price elasticity of demand between fuel chips and pulpwood, and the likely impacts of federal renewable energy standards on the economic incentives that drive project development. In addition, further study is needed to explore the relation biomass sourcing has on harvest intensity and the potential impacts on forest biodiversity, wildlife habitat, water quality, and soil health and productivity.

2. TECHNOLOGY PATHWAYS

This discussion focuses on those technologies and applications—electricty generation and CHP—that are already well established, or are technologically achievable in the immediate future should policies wish to guide additional biomass in these directions.

2.1.0 INTRODUCTION TO TECHNOLOGY PATHWAYS

Biomass in various forms can be used for a range of energy options, through a variety of technologies, to achieve various end purposes. In this chapter, several pathways are examined to give the reader an understanding of this range, but also to inform and model potential demand for fuel supply in the future and understand the carbon implications for these choices. This assessment looks at the use of existing low-grade forest resources in the seven-state study region as well as switchgrass, an agricultural crop that can also be pelletized and used directly for biomass energy. Other sources of nonforest-based biomass—such as wood waste from construction debris or other sources sometimes considered as biomass, such as municipal waste—were also considered. The analysis of switchgrass was based on information from a literature review that did not provide adequate or comparable information to what was available from our forest biomass modeling. The switchgrass analyses in this report are incomplete and are included for information and comparative purposes only.

With respect to the forest's low-grade wood resource potentially used for energy, the end products can be solid (cordwood, woodchips, or wood pellets), liquid (pyrolysis oil or cellulosic ethanol), or gas (synthetic or producer gas made through "gasification" and "bio-char" technologies). The end uses can also range from residential to industrial applications, and fall into three general categories: electricity power production, thermal applications for heating or using thermal heat for space cooling in vapor absorption chillers, or emerging technologies such as cellulosic ethanol or gasification. Between the first two end-use categories is combined heat and power (CHP), which can be thermal-led (optimizing heat production with some electricity produced) or electricity-led (sizing the plant for optimal electricity production and using some of the heat).

Some of these technologies and applications are well established and have been in place for years. Others are pre-commercial or still under development. In the sections that follow, we describe two main currently available applications for electricity and CHP. This discussion focuses on those technologies and applications that are already well established, or are technologically achievable in the immediate future should policies wish to guide additional biomass in these directions. These are the applications most likely to place demands on southeastern forest resources in the short term.

Among these application areas, 12 technology pathways were selected to describe how biomass might be used. These pathways are used to evaluate and compare different scenarios for forest management and carbon impacts if policies are directing biomass use toward stand-alone electrical generation, and to enable comparison to the most likely fossil fuel alternatives (out of which four fossil fuel pathways were chosen). The pathways and full data assumptions are displayed in Appendix A.

2.1.1 ELECTRICITY GENERATION

2.1.1.2 Current Sources of Electrical Supply

The seven-state region produced a total of 858,238,084 megawatt hours (MWH) of electricity in 2009, the most recent year for which full data is available (EIA, 2011). Of the total electrical generation in the region, 38 percent is generated by coal power plants (345,882,814 MWH). The second largest electrical source for the region is nuclear power, comprising 29 percent of the total regional generation (248,688,358 MWH). Although natural gas is the largest fuel source for electrical generation in Florida, for the seven-state study region it is the third largest fuel source for electrical generation with 197,687,923 MWH (28 percent of total regional generation). Renewable energy accounts for only 6 percent of electrical generation in the seven-state area, with hydroelectric plants producing 4 percent of the regional electrical generation. The state energy profiles produced by the EIA do not tabulate statistics for biomass electrical generation, which is included in the category of "other renewables" and which accounts for 2 percent of the regional electrical generation.

Tables 12-18 below and on the following pages summarize the state electrical generation profiles for 2009.

Table 12. Virginia Electrical Generation Profile

Total Electric Industry	**70,082,066**
Coal	25,599,288
Petroleum	1,087,660
Natural Gas	12,201,384
Other gases[15]	-
Nuclear	28,212,252
Hydroelectric	1,478,630
Other renewables[16]	2,417,519
Pumped Storage	-1,334,709
Other[17]	420,042

2. TECHNOLOGY PATHWAYS *(cont'd)*

Table 13. North Carolina Electrical Generation Profile	
Total Electric Industry	**118,407,403**
Coal	65,082,782
Petroleum	296,859
Natural Gas	4,851,885
Other gases[15]	-
Nuclear	40,847,711
Hydroelectric	5,171,257
Other renewables[16]	1,893,404
Pumped Storage	43,077
Other[17]	220,428

Table 14. South Carolina Electrical Generation Profile	
Total Electric Industry	**100,125,486**
Coal	34,477,512
Petroleum	523,484
Natural Gas	9,780,193
Other gases[15]	-
Nuclear	52,149,734
Hydroelectric	2,332,005
Other renewables[16]	1,747,971
Pumped Storage	-976,443
Other[17]	91,029

Table 15. Florida Electrical Generation Profile

Total Electric Industry	**217,952,308**
Coal	54,003,072
Petroleum	9,221,017
Natural Gas	118,322,308
Other gases[15]	6,800
Nuclear	29,117,877
Hydroelectric	208,202
Other renewables[16]	4,340,332
Other[17]	2,732,701

Table 16. Georgia Electrical Generation Profile

Total Electric Industry	**128,698,376**
Coal	69,478,196
Petroleum	649,674
Natural Gas	20,505,749
Other gases[15]	-
Nuclear	31,682,579
Hydroelectric	3,259,683
Other renewables[16]	2,825,170
Pumped Storage	271,988
Other[17]	25,337

2. TECHNOLOGY PATHWAYS *(cont'd)*

Table 17. Alabama Electrical Generation Profile

Total Electric Industry	**143,255,556**
Coal	55,608,724
Petroleum	219,274
Natural Gas	31,617,083
Other Gases[15]	134,728
Nuclear	39,716,204
Hydroelectric	12,535,373
Other Renewables[16]	3,049,857
Other[17]	374,314

Table 18. Tennessee Electrical Generation Profile

Total Electric Industry	**79,716,889**
Coal	41,633,240
Petroleum	186,930
Natural Gas	409,321
Other gases[15]	12,010
Nuclear	26,962,001
Hydroelectric	10,211,962
Other renewables[16]	950,468
Pumped Storage	-649,832
Other[17]	788

2.1.2 CURRENT BIOMASS POWER PLANTS

The region is home to 17 biomass electrical plants. Detailed information is available for 12 of these plants, with a total capacity of 246 megawatts (Oak Ridge National Laboratory, 2011).

Table 19. Current Biomass Power Plants

Plant Name	State Name	Capacity MW	Online Year
Bryant Sugar House	Florida	6.63	1962
Stone Container Florence Mill	South Carolina	7.63	1963
DG Telogia Power	Florida	12.50	1986
Stone Container Hopewell Mill	Virginia	20.35	1980
Jefferson Power LLC	Florida	7.50	1990
Craven County Wood Energy LP	North Carolina	45.00	1990
Port Wentworth	Georgia	21.60	1991
Ridge Generating Station	Florida	47.10	1994
Multitrade of Pittsylvania LP*	Virginia	26.55	1994
Okeelanta Cogeneration	Florida	24.97	1996
Scott Wood	Virginia	0.80	2003
Buckeye Florida	Florida	25.00	2006
	Average Capacity	**20.47**	
	Total Capacity	**245.63**	

** This plant is now owned by Dominion and has a 79 MW capacity. Dominion has announced it will increase its wood requirement to 850,000 green tons/year.*

2. TECHNOLOGY PATHWAYS *(cont'd)*

2.2.0 SUMMARY OF PATHWAYS

Pathways #1-4 describe using woodchip fuel for electrical generation.

Pathway #1 describes the average existing biomass electrical generating facility, with a typical size of 20 MW and a typical efficiency of 26 percent.

Pathway #2 describes a typical new biomass plant as proposed in the region, with a larger plant capacity of 50 MW and a higher efficiency of 28 percent.

Pathway #3 considers co-firing woodchips with coal in existing coal power plants at a balance of 10 percent woodchips and 90 percent coal. Biomass co-firing in existing coal plants would utilize biomass fuels with much lower capital investment than constructing new electrical generating stations designed to burn woodchips.

Pathway #4 considers a CHP application in a 5 MW facility with 75 percent total efficiency.

Pathways #5-7 consider using switchgrass pellets for electrical generation. The pelletization of switchgrass for use in boilers and other combustion systems is still under development. While switchgrass pellets are used in some thermal applications and have been test fired in electrical generating plants, no switchgrass electrical generation exists. Since this option is hypothetical and for the purpose of comparing the carbon implications of different types of biomass fuels, the switchgrass pathways were assumed to have the same capacities as the woodchip-fueled plants with which they are being compared.

Pathway #5 considers a 50 MW plant comparable to the new woodchip electrical generating plants considered in pathway #2.

Pathway #6 considers co-firing 10 percent switchgrass in existing coal plants.

Pathway #7 considers a CHP plant of 5 MW.

The analysis of switchgrass was based on information from a literature review that did not provide adequate or comparable information to what was available from our forest biomass modeling. The switchgrass analyses included in this report are incomplete and are included for information and comparative purposes only.

Pathways #8-10 explore electrical generation with coal.

Pathway #8 considers an average coal plant existing in the region with a capacity of 450 MW (rounded from regional average to nearest 50 MW) and an efficiency of 33 percent.

Pathway #9 considers a larger (600 MW), slightly more efficient (36 percent) coal plant typical of the size and type proposed for new coal plants in the region.

Pathway #10 is a theoretical option considering a coal CHP project similar to the proposed biomass CHP projects in pathways #4 and #7.

Pathway #11 considers a large natural gas electrical plant with an 800 MW capacity and 42 percent efficiency as representative of new natural gas plants proposed for the region.

A 12th scenario, **Pathway 2A**, was also considered as an alternative energy end use for woody biomass. Woody biomass pelletization was considered versus combustion of biomass for power generation. The pellets would most likely be exported to Europe for combustion for either heating or power generation. This scenario considers the additional carbon emissions if the biomass from the southeast region is used to make pellets, and those pellets are exported across the Atlantic to Europe and used to generate power there. Wherever they are burned, the pellets produce 765.9 pounds of CO_2 per MMBtu when combusted for electrical generation. Additional emissions result from the energy consumed in making pellets and for transportation across the Atlantic. 26.74 pounds of CO_2 would be released in the Southeast in the process of pellet production per MMBtu of pellets produced. Another 11.55 pounds of CO_2 would be released in transport from production facility to US ports and from European ports to electrical generation plants. An additional 25.87 pounds of CO_2 per MMBtu of pellets would be emitted in cross-Atlantic transport. In this scenario, some of the carbon emissions involved in pelletization would occur in the Southeast, but a good deal of the carbon emissions would occur in transportation and in Europe when the pellets are combusted.

The carbon emissions from pellet production and transport to the final end use were compared to the emissions from production and transport of woodchips (16.5 pounds per MMBtu of output), switchgrass (16.5 pounds per MMBtu of output), coal (21.3 pounds per MMBtu output), and natural gas (80.4 pounds per MMBtu of output) (Manomet, 2010). These emissions include harvesting or mining, refining and/or other fuel processing, and transport from the site of harvest or collection to processing sites, then to southeastern power plants. The carbon emissions from each fuel source for production and transportation are displayed in Table 24 on page 62.

2.2.1 Electrical Generation Pathways

Table 20 below presents the CO_2 emissions from electrical generation from the nine electrical technology pathways.

Table 20. Electrical Generation Pathway CO_2 Emissions

Electrical Generation Pathway	CO_2 Emissions (lbs/MMBtu output)
Wood (existing plants)	859
Wood (new plants)	783
Wood (exported pellets)	1,010
Coal/wood Co-firing	677
Switchgrass	829
Coal/switchgrass co-firing	669
Coal (existing plants)	643
Coal (new plants)	587
Natural gas	359

Of all the fuels considered, natural gas is the cleanest and the lowest carbon emitting due to its ability to generate power using a direct combustion turbine at higher efficiency than traditional steam turbine technologies, and the fact that it has less carbon per unit of energy.

2. TECHNOLOGY PATHWAYS *(cont'd)*

2.2.2 CHP Options

All electrical production from combustion of fuels creates excess heat that is often wasted. In the case of power plants, excess heat is often simply released as steam from the turbine, condensed, and returned to the boiler. CHP systems seek to utilize some or all of this excess heat. As this excess heat is made into useful energy, the efficiency of the generating system increases with the proportion of heat it uses.

Electricity-led CHP is an option where power production is near a thermal demand. A 20 MW power plant produces enough heat to heat approximately 1,100 homes.[18] To date, however, the economics, incentives, and siting preferences have not resulted in power plants choosing CHP. As a result, regardless of the fuel source producing the electricity, approximately 65-75 percent of the energy value of the fuel in conventional combustion systems has been wasted as lost heat. Taking advantage of this energy value requires planning, intentional siting, and either financial or regulatory incentives that promote power producers deciding to increase the complexity of their systems by the addition of steam or hot water as a salable output. This is not the business model that has been pursued to date. Recently, with the increased appreciation of efficiency and concern about efficient use of resources, biomass power developers are beginning to incorporate some CHP in their proposals, though because of the large amount of heat available relative to potential nearby uses, these projects often make use of only a small percentage of the available heat (10-15 percent).

In contrast, thermally led CHP maximizes the demand for heat, but produces relatively little electricity. At the community scale, a typical CHP facility might produce 1-5 MW of electricity while providing enough steam for process heat and/or cooling for a small industrial park.

An important point to note is that the cost-effective scale of producing electricity alone leads to plants in the 20-50 MW size range. At this scale, it is most cost effective to produce the power, and any CHP component is a complicating factor that tends to reduce the overall cost effectiveness of the project under current policies that subsidize electrical production but do not subsidize or reward thermal energy production. At smaller-scale thermal-led CHP systems of 1-5 MW, the opposite is true—production of heat alone maximizes cost effectiveness of the project, and adding an electrical component reduces the overall economics of the project, i.e., the savings in heat help subsidize the electrical generation components.

Conventional technology requires the production of steam to produce electricity, but European commercial technologies produce electricity without steam production. These technologies include gasification where the produced gas is combusted directly in a combustion turbine, and Organic Rankine Cycle (ORC) thermal-oil technology that uses a thermal oil to gain temperature gradients necessary to produce electricity without steam so that the thermal system can be designed around low-pressure hot water. The ORC system, while more easily incorporated into a hot water-based thermal application and therefore of greater potential in smaller CHP systems (see below), is

still only approximately 20 percent efficient on its own in the production of electricity, but would be expected to be between 75-85 percent efficient in heat-led applications. Heat-led gasification can be expected to be approximately 75 percent efficient.

Pathways #4, #7, and #10 describe moderate-sized CHP systems capable of producing 5.0 MW of electricity. The first uses conventional technology, producing steam to run a turbine, and fully utilizes the 34 MMBtu/hour of heat generated to heat facilities on the order of magnitude of a college campus, a hospital, or small community. As such, the overall efficiency is rated at 75 percent, which is typical for such units. The second pathway uses gasification technology, which is just an emerging technology here in the United States. Still, there is an example of a commercial system operating since 2000 in the Town of Harboøre, Jutland, Denmark that produces 1.6 MW of electricity and heats 900 homes (BERC, 2010). The efficiency rating for this system is also 75 percent.

Table 21 below presents CO_2 emissions from energy conversion for the three CHP pathways considered.

Table 21. CHP Pathway CO_2 Emissions

CHP Pathway	CO_2 Emissions (lbs/MMBtu)
Wood	296
Switchgrass	314
Coal	295

2. TECHNOLOGY PATHWAYS *(cont'd)*

2.3.0 EFFICIENCY

As has been discussed throughout, the efficiency with which energy value is extracted from biomass—or fossil fuel—varies according to the energy product sought and the technology pathway used to make that product. Figure 4 and Table 22 on the following pages show the range of efficiencies for the different applications and pathways selected, from most efficient to least efficient on a gross heat efficiency basis. The electrical efficiency for each option shows the percent of total energy in the fuel source that is converted into electricity. The gross thermal efficiency is the total efficiency for each option, including both the electrical efficiency and any energy captured and used as thermal energy.

It is important to recognize that what is presented is just the efficiency of the process to produce energy or fuel or product from the biomass. This does not include any losses incurred through the use of the end product. For example, for electricity, these efficiencies do not include line losses or the efficiency of a given appliance to turn remaining electricity into useful work. Similarly, for the transportation fuels, this does not include the relative inefficient (18 percent) ability of your car to take the energy value of the fuel and convert it into the work of moving you down the road. Finally, for the thermal applications, it does not include the loss of heat exchange from the thermal system to a home, or the efficiency of a home to retain heat. These examples show that further down the process more losses of the energy value of the original biomass will be incurred. They may be smaller or they may be quite large, depending on the end uses.

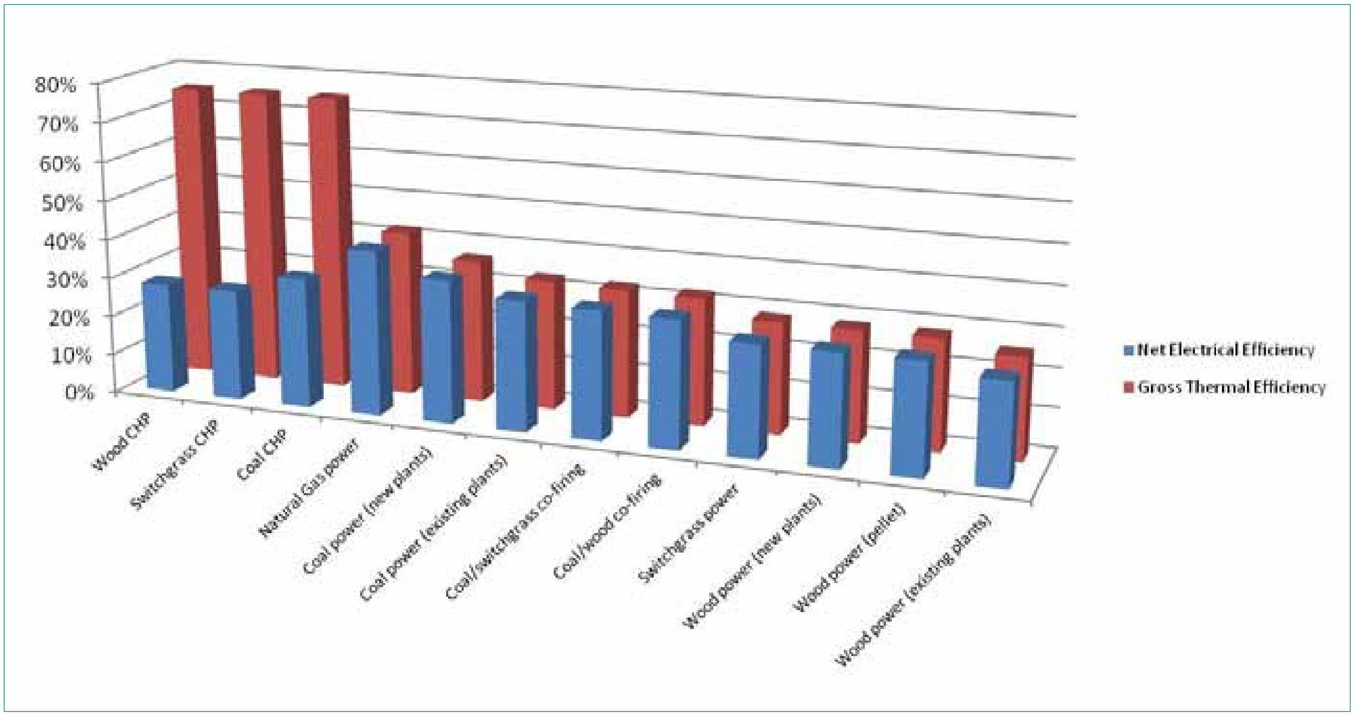


Figure 4.

Graph of Efficiency of 12 Technology Pathway Options.[19]

Table 22. Efficiency of 12 Technology Pathway Options[20]

Technology Pathway	Net Electrical Efficiency	Gross Thermal Efficiency
Wood CHP	28.2%	75.0%
Switchgrass CHP	28.2%	75.0%
Coal CHP	33.0%	75.0%
Natural Gas power	42.0%	42.0%
Coal power (new plants)	36.3%	36.3%
Coal power (existing plants)	33.0%	33.0%
Coal/switchgrass co-firing	32.5%	32.5%
Coal/wood co-firing	32.3%	32.3%
Switchgrass power	28.2%	28.2%
Wood power (new plants)	28.2%	28.2%
Wood power (pellet)	28.2%	28.2%
Wood power (existing plants)	25.6%	25.6%

2. TECHNOLOGY PATHWAYS *(cont'd)*

2.4.0 CARBON IMPACTS

The CO_2 emissions from each of the pathways vary depending on the fuel and the efficiency of the product made. The CO_2 emissions expressed as "input" energy and the CO_2 emissions based on "output" energy reflect the efficiency of the biomass energy conversion. The carbon content on an input basis reflects only the carbon content of the fuel on a pounds per MMBtu of energy content basis before the fuel is combusted. The carbon emissions on an output basis also reflect the efficiency of the energy generation process, and reflect how much carbon has been emitted into the atmosphere after the fuel has been combusted. The input CO_2 emissions are a measure only of the pre-combustion carbon content of the fuel, while the output emissions calculate the total CO_2 emissions once the fuel has been combusted and utilized in a particular manner.

The tables and figures on the following pages reflect the different pathways. The CO_2 emissions from fuel to energy conversion are presented first on an input and output basis, followed by the CO_2 emissions from production and transportation of fuel associated with each pathway on an input and output basis, then the total CO_2 emissions for each pathway on an output basis are compared.

The emissions from production and transportation for the pellet scenario exceed the emissions due to production and transportation from any other fuel type. This is due to the assumption that the pellets will be transported to European markets for final consumption, adding 25.87 pounds of CO_2 per MMBtu of pellets. With very low-heating demands in the climate of the Southeast, however, exporting the pellets would indeed be the most likely scenario unless used for power production domestically.

As with the efficiency discussion, it is very important to note that the following tables and figures do not reflect a life-cycle analysis of these technology pathways, merely the carbon emissions resulting from the fuel-to-energy conversion and the emissions from production and transportation. While full carbon life-cycle accounting for all pathways is beyond the scope of this report, life-cycle estimates of carbon emissions for the technological options considered in Chapter 3 are provided there.

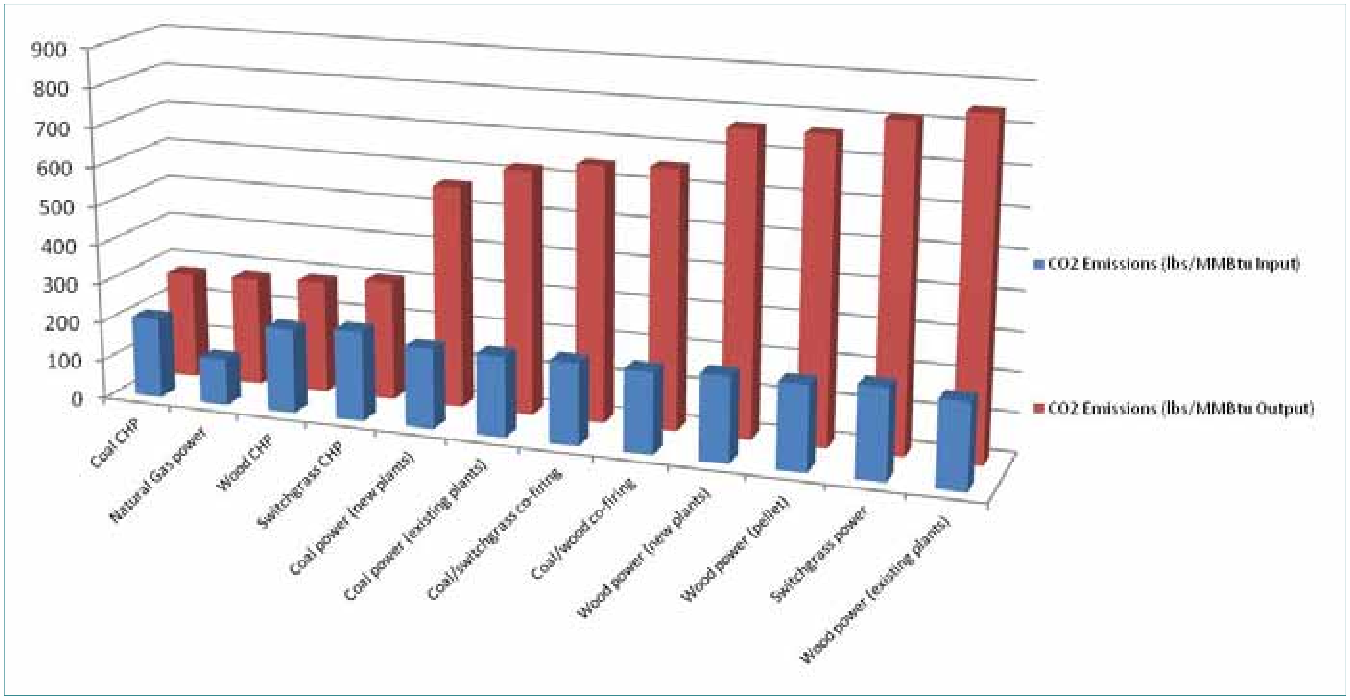


Figure 5.

Graph of CO_2 Emissions from Energy Conversion of 12 Technology Pathways.[21]

Table 23. CO_2 Emissions from Energy Conversion of 12 Technology Pathways[22]

Technology Pathway	CO_2 Emissions (lbs/MMBtu Input)	CO_2 Emissions (lbs/MMBtu Output)
Coal CHP	205.3	273.7
Natural Gas power	117.0	278.6
Wood CHP	215.7	287.6
Switchgrass CHP	229.2	305.6
Coal power (new plants)	205.3	565.6
Coal power (existing plants)	205.3	622.1
Coal/switchgrass co-firing	207.7	648.4
Coal/wood co-firing	206.3	656.3
Wood power (new plants)	215.7	765.9
Wood power (pellet)	215.7	765.9
Switchgrass power	229.2	812.6
Wood power (existing plants)	215.7	842.5

2. TECHNOLOGY PATHWAYS *(cont'd)*

Figure 6.

Graph of CO_2 Emissions from Fuel Production and Transportation of 12 Technology Pathways[23]

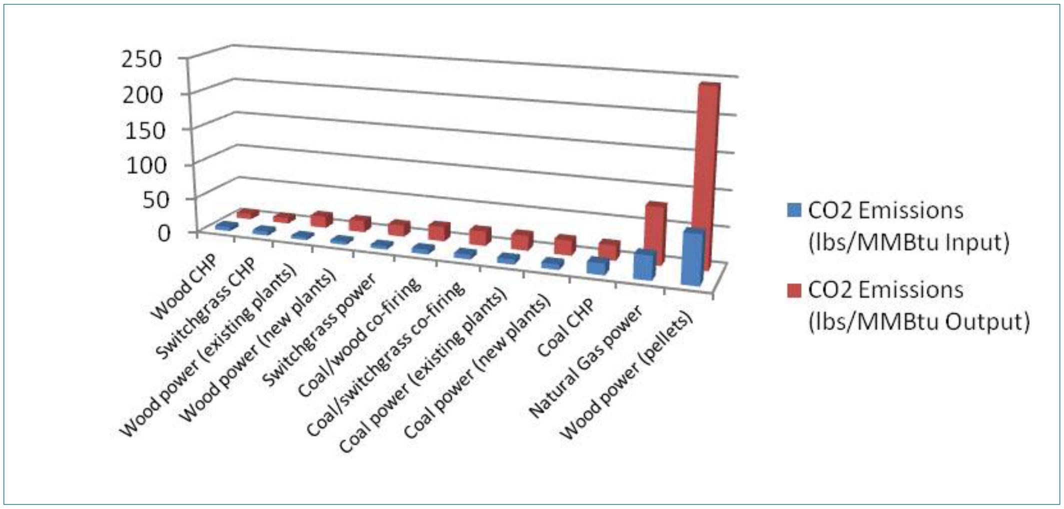


Table 24. CO_2 Emissions from Fuel Production and Transportation of 12 Technology Pathways[2]

Technology Pathway	CO_2 Emissions (lbs/MMBtu Input)	CO_2 Emissions (lbs/MMBtu Output)
Wood CHP	6.1	8.1
Switchgrass CHP	6.1	8.1
Wood power (existing plants)	4.2	16.5
Wood power (new plants)	4.7	16.5
Switchgrass power	4.7	16.5
Coal/wood co-firing	6.6	20.8
Coal/switchgrass co-firing	6.7	20.8
Coal power (existing plants)	7.0	21.3
Coal power (new plants)	7.7	21.3
Coal CHP	16.0	21.3
Natural Gas power	33.8	80.4
Wood power (pellets)	68.8	244.4

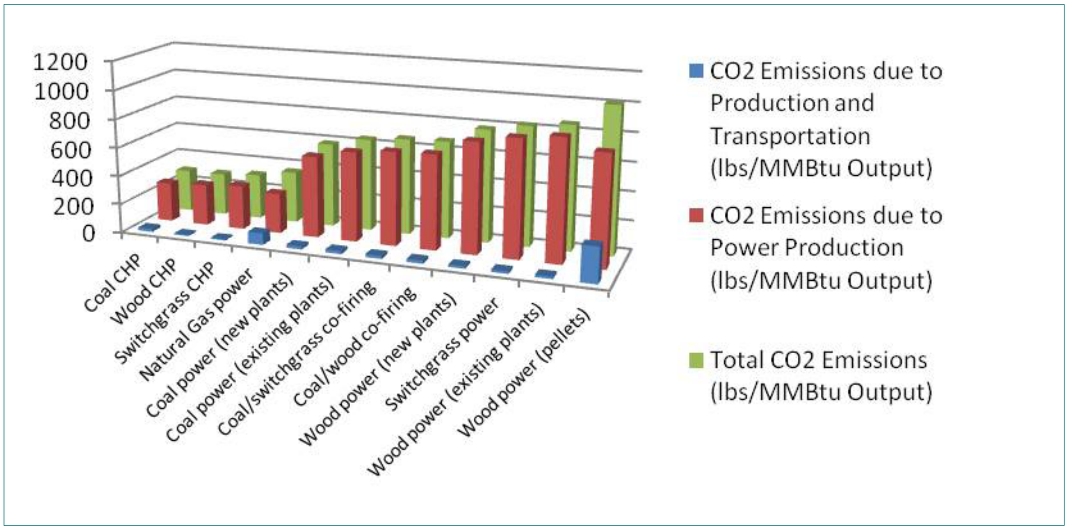


Figure 7.

Graph of Total CO_2 Emissions on Energy Output Basis of 12 Technology Pathways[25]

Table 25 . Total CO_2 Emissions on Energy Output Basis of 12 Technology Pathways[26]

Technology Pathway	CO_2 Emissions due to Production and Transportation (lbs/MMBtu Output)	CO_2 Emissions due to Power Production (lbs/MMBtu Output)	Total CO_2 Emissions (lbs/MMBtu Output)
Coal CHP	21.3	273.7	295.0
Wood CHP	8.1	287.6	295.6
Switchgrass CHP	8.1	305.6	313.6
Natural Gas power	80.4	278.6	359.0
Coal power (new plants)	21.3	565.6	586.8
Coal power (existing plants)	21.3	622.1	643.4
Coal/switchgrass co-firing	20.8	648.4	669.2
Coal/wood co-firing	20.8	656.3	677.1
Wood power (new plants)	16.5	765.9	782.5
Switchgrass power	16.5	812.6	829.2
Wood power (existing plants)	16.5	842.5	859.1
Wood power (pellets)	244.4	765.9	1010.3

2. TECHNOLOGY PATHWAYS *(cont'd)*

2.5.0 N_2O IMPACTS

Nitrous oxide (N_2O) is a greenhouse gas with an atmospheric lifetime of approximately 120 years. Nitrous oxide is about 310 times more effective in trapping heat in the atmosphere than CO_2 over a 100-year period (EPA, 2011). EPA also reports that in 2009, 25 percent of total N_2O emissions in the United States came from fossil fuel combustion. There are currently no state or federal regulations regarding N_2O emissions. For the fuel types and energy conversion processes studies, the N_2O emissions, even on a CO_2 -equivalent basis, were insignificant compared to the CO_2 emissions.

Like the carbon emissions just mentioned, the N_2O emissions from each of the pathways vary depending on the fuel and the efficiency of the product made. Generally, the N_2O emissions expressed as "input" energy reflect the fuel the process is based on, and the N_2O emissions based on "output" energy reflect the efficiency of the product conversion, be that electricity, thermal, or fuel. Unlike the carbon accounting, the N_2O emissions calculations do not include the additional N_2O emissions from production and transport of fuels, only the energy conversion of each fuel in each pathway.

As with the efficiency and carbon discussions, it is very important to note this is not a life-cycle analysis of these technology pathways.

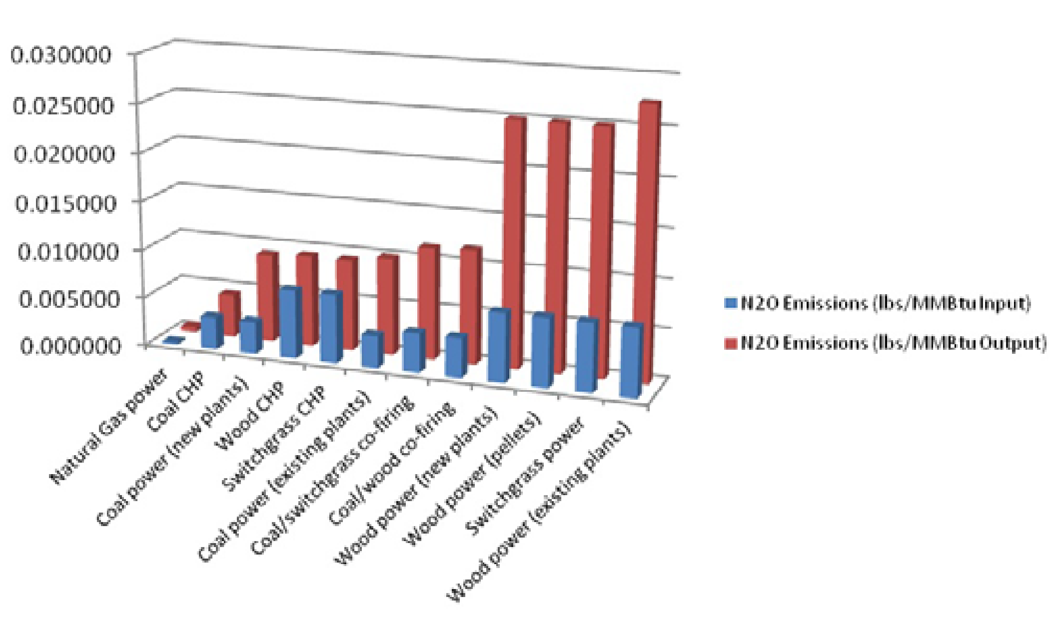


Figure 8.

Graph of N_2O Emissions of 12 Technology Pathways.[27]

Table 26. N_2O Emissions of 12 Technology Pathways[28]

Technology Pathway	N2O Emissions (lbs/MMBtu Input)	N2O Emissions (lbs/MMBtu Output)	Output N2O Emissions as Tons of CO2 Equivalent
Natural Gas power	0.000220	0.00052	0.0001
Coal CHP	0.003306	0.00441	0.001
Coal power (new plants)	0.003306	0.00911	0.001
Wood CHP	0.007054	0.00941	0.001
Switchgrass CHP	0.007054	0.00941	0.001
Coal power (existing plants)	0.003306	0.01002	0.002
Coal/switchgrass co-firing	0.004056	0.01150	0.002
Coal/wood co-firing	0.004056	0.01171	0.003
Wood power (new plants)	0.007054	0.02505	0.003
Wood power (pellets)	0.007054	0.02505	0.003
Switchgrass power	0.007054	0.02505	0.003
Wood power (existing plants)	0.007054	0.02755	0.004

3. ATMOSPHERIC CARBON ANALYSIS

3.1.0 SUMMARY

Spatial Informatics Group has provided an atmospheric carbon-balance analysis of biomass feedstock for this study. This analysis was conducted for biomass stand-alone electric power and electric-led CHP applications. Thermal energy pathways, which have significantly different life-cycle carbon due to higher efficiencies, were not considered in this analysis. We produced an analysis of existing and proposed biomass electric power facilities in the context of a forested landscape. The study area encompassed more than 88 million acres over seven states.

This study used carbon accounting principles that are consistent with accepted forest carbon protocols to examine the consequences of atmospheric carbon balance relative to a baseline that is geographically constrained to the affected area.

Our findings indicate that in the current situation, 17 biomass electric facilities generate 159 megawatts and pellet manufacturers produce 1,775,000 tons of pellets. The megawatts are generated here in the United States and the pellets are manufactured here with some shipped to domestic plants but most bound for Europe. The facilities we examined were producing improved atmospheric carbon balance relative to using other energy fuels and technologies to provide equivalent power at a landscape scale. We modeled an additional 22 biomass power facilities that would generate 1,014 MW of electricity and pellet plants that produce 3,050,000 tons of pellets (mostly shipped to Europe) to represent the proposed expansion (as of May 2011) of the biomass electric-generating sector in the Southeast in the next several years. These additional biomass facilities were also favorable relative to the alternatives, in the long term, because of the sustained production of wood fiber, assuming all stands are replanted or naturally regenerated to achieve full restocking, and no forest land conversion. A carbon debt period of 35-50 years, however, was required for woody biomass to achieve a beneficial atmospheric carbon profile relative to the other pathways examined at a landscape scale.

This multi-decade carbon debt period is consistent with other studies (Manomet 2010, McKechnie 2011) that have used life-cycle analysis, forest carbon accounting, and a "business-as-usual" baseline to compare biomass to other forms of energy production. The Manomet modeling produced a 42-year payback period for biomass versus coal-generated electricity, and the McKechnie modeling indicated 17-38 year payback periods for generating electricity with biomass instead of coal. Although these patterns are basically consistent, the actual differences in debt periods are expected in different forest types and harvest scenarios. In addition, our model includes a more precise modeling of actual harvesting methods in real stands distributed across the landscape and linked to specific facilities. There are significant differences in the payback periods required to re-sequester all the emitted carbon and return to what may be termed a "carbon-neutral" situation. Our modeling indicates a 53-year time period while the Manomet results for Massachusetts indicate more than 100 years are required.

Assumptions regarding the required biomass supply per unit of power produced an effect on the atmospheric carbon balance for the build-out of the proposed facilities. A higher figure for biomass per unit of power produced showed that the number of years was extended before biomass was shown to be better than fossil fuels.

Naturally regenerated hardwood forest types were also shown to store as much or more carbon on a per-acre basis than most other forest types and plantations, even when regularly harvested for biomass in integrated sawtimber and pulpwood harvests. Tradeoffs between utilizing pulpwood and residuals for biomass energy were found to be most appropriately addressed at project- or stand-level scales.

This study suggests that the atmospheric carbon balance of biomass electric power is better in the long term relative to fossil fuel pathways. A period of decades is required, however, to achieve this result due to the changes in the stored carbon on the landscape relative to a baseline. As biomass demand increases with more facilities beyond the 22 currently proposed, the ability of the forested landscape to provide biomass supply and store carbon may become more limited, particularly in localized areas with strong demand. As this occurs, other factors may become more important in determining the atmospheric carbon balance of biomass energy such as the extent to which biomass demand drives new forest conversion or diversion of wood from other existing uses.

3.2.0 INTRODUCTION

One of the major tasks of this study is to provide a landscape life-cycle analysis of three major feedstocks under two likely scenarios for biomass electric power and electric-led CHP.

This chapter addresses the landscape carbon life-cycle analysis. It provides a section on introduction, methods, and findings. Technical details are presented in the appendix. An executive summary that addresses the full scope of the project that integrates all the tasks is also provided. Eight specific questions were posed to the research team for analysis:

1. What are the GHG consequences of operating the existing 17 biomass power plants in the study region versus not running them into the future and using fossil fuel instead?
2. What are the GHG consequences of operating the existing biomass power plants as compared to operating these existing plants plus 22 new proposed biomass power plants?
3. What are the GHG consequences of varying the amounts of biomass required to make a specific amount of electricity?
4. What are the GHG consequences of using forest-derived biomass versus non forest-derived biomass?
5. What are the GHG consequences of using tops and limbs (residuals) for biomass supply versus pulpwood (main stems)?
6. What are the GHG consequences of using natural stands versus plantations to fuel an expansion of biomass electric power in the Southeast?
7. What are the GHG consequences of varying levels of pellet export to Europe for electric power generation from the Southeast?
8. Is there enough biomass available to supply 22 new biomass facilities while limiting the amount of residuals that can be removed to protect forest health?

3. ATMOSPHERIC CARBON ANALYSIS *(cont'd)*

3.3.0 METHODOLOGY

This analysis examined the GHG implications of biomass electric generation scenarios for a study area in the southeastern United States. The study area included four eco-sections representing a large portion of the Southeast (see Figure 9 on the opposite page). The study was restricted to these eco-sections to keep the analysis workload reasonable while allowing a large and representative portion of the region to be studied. The following discusses the facilities studied, technology pathways considered, forest growth simulations, and carbon-accounting simulations.

To understand the GHG implications of increased demand, we examined 17 existing facilities and the addition of 22 new biomass electric power facilities to represent the proposed expansion of the biomass electric sector in the Southeast. In order to inform the question of GHG impacts of biomass energy, we examined the GHG implications of the emissions associated with burning biomass feedstock from the forest in relation to other sources of fuel and technology pathways. We also conducted sensitivity analyses on a number of factors to understand how the GHG accounting might be affected.

The atmospheric carbon analysis was divided into specific sub-tasks that were used to produce the work in this report. The subtasks are described in the following sections with detailed information provided in the appendix. Below is a list of the sub-tasks:

- Sub-Task 1. Geospatial Analysis
- Sub-Task 2. Definition of Silvicultural Prescriptions for Eco-Regions, Forest Types, and Stand Origin
- Sub-Task 3. Inventory Data Preparation
- Sub-Task 4. Forest Modeling
- Sub-Task 5. Carbon Accounting
- Sub-Task 6. Definition of Landscape and Facilities-Modeling Framework
- Sub-Task 7. Integration of Geospatial and Attribute Data
- Sub-Task 8. Carbon Landscape Analysis
- Sub-Task 9. Sensitivity Analysis
- Sub-Task 10. Draft Final Report
- Sub-Task 11. Final Report

3.3.1 Geospatial Analysis

The purpose of this task was to generate spatial data that allowed the study to be conducted at the landscape level using an integrated all-lands approach. This analysis produced information that reflected the realities of the landscape as they exist today with no assumptions made about land-use change or changing market dynamics. This task quantified vegetation type, transportation distances, constraints on forest management, and operational restrictions as they currently exist in the region. What follows is a summary.

Vegetation Type

There were four eco-sections used for analysis, which may be found in Description of Ecological Subregions: Sections of the Conterminous United States (McNab et al., 2005). Figure 9 on the next page shows the location of these eco-sections with the major forest types. Table 27 on the next page shows the acres estimated from the Forest Inventory and Analysis (FIA) databases for each eco-section and forest-type group.

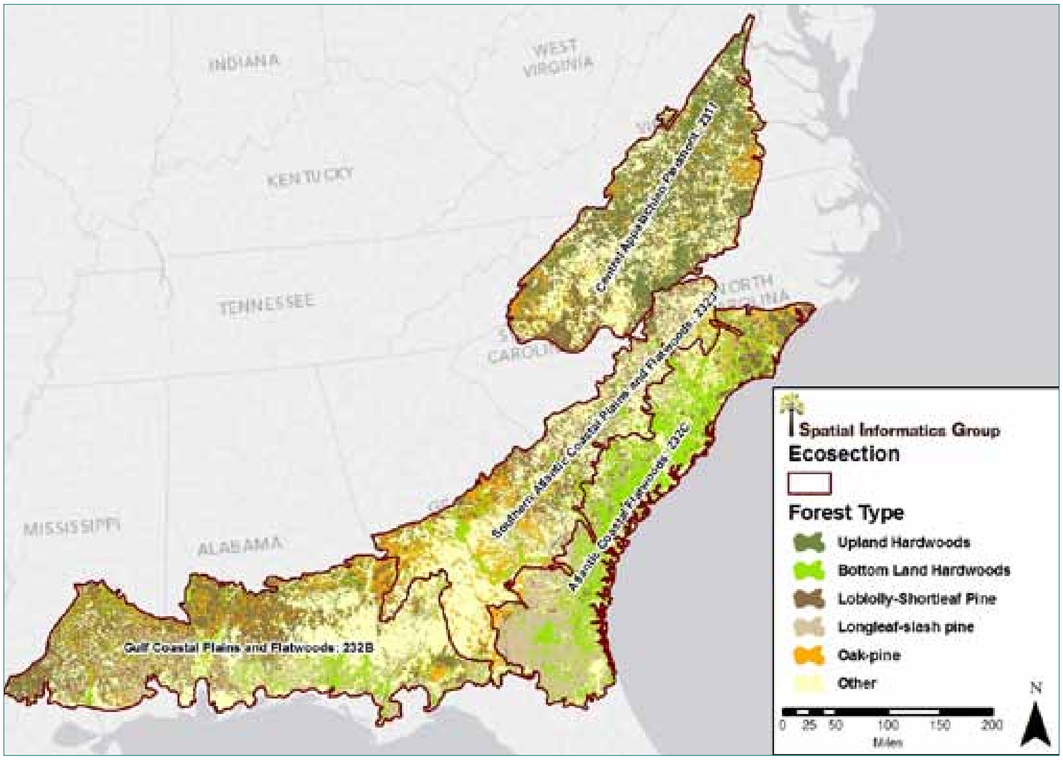


Figure 9.

Map of eco-sections and forest types within the study area. The study area was composed of the four eco-sections shown.

Table 27. Acres by Forest-Type Group, Stand Origin, and Eco-Section

Forest-Type Group	231I-Central Appalachian Piedmont	232B-Gulf Coastal Plains and Flatwoods	232C-Atlantic Coastal Flatwoods	232J-Southern Atlantic Coastal Plains and Flatwoods
Bottomland Hardwoods	629,766	2,735,943	3,118,925	2,418,890
Loblolly/Shortleaf Natural	1,431,249	2,086,954	1,371,449	1,374,118
Loblolly/Shortleaf Plantation	1,748,837	4,574,524	2,459,067	2,673,421
Longleaf/Slash Natural	4,349	928,478	513,542	695,605
Longleaf/Slash Plantation	260	1,124,209	1,835,337	1,061,007
Upland Hardwood-Oak Hickory	5,832,079	3,866,263	1,025,381	2,257,467
Mixed Pine-Oak Natural	1,350,490	1,754,184	1,002,367	1,182,812
Mixed Pine-Oak Plantation	215,802	610,307	260,002	248,034

Source: FIA (2011)

3. ATMOSPHERIC CARBON ANALYSIS *(cont'd)*

Section 231I-Central Appalachian Piedmont. This section is east of the Blue Ridge Mountains in central Virginia and North Carolina. It belongs to the Southeastern Mixed Forest Province (231), which "has generally uniform climate with mild winters and hot, humid summers. Annual precipitation is evenly distributed, but a brief period of mild-to-late summer drought occurs in most years." It has high and low hills with deep weathered soils. Forest vegetation is loblolly-shortleaf pine and oak-hickory types. The Central Appalachian Piedmont section is 32,806 square miles.

Section 232B-Gulf Coastal Plains and Flatwoods. This section extends along the Gulf of Mexico coast from southwestern Georgia and the Florida panhandle west through southern Alabama and ending in southern Louisiana. It belongs to the Outer Coastal Plain Mixed Forest Province (232), which "is an eco-region of humid, maritime climate; winters are mild and summers are warm. Precipitation is abundant with rare periods of summer drought. Upland forest vegetation is dominated by conifers, with deciduous hardwoods along major floodplains." It has a flat weakly dissected landscape of irregular or smooth plains. Vegetation is mainly longleaf-slash pine, loblolly-shortleaf pine, and oak-hickory cover types with oak-gum-cypress along rivers. The Gulf Coastal Plains and Flatwoods section is 43,495 square miles.

Section 232C-Atlantic Coastal Flatwoods. This section extends along the Atlantic coast from southern North Carolina south through South Carolina and Georgia into the northeastern part of Florida. This section belongs to the Outer Coastal Plain Mixed Forest Province (232), which "is an eco-region of humid, maritime climate; winters are mild and summers are warm. Precipitation is abundant with rare periods of summer drought. Upland forest vegetation is dominated by conifers, with deciduous hardwoods along major floodplains." It is a weakly dissected flat alluvial plain. Vegetation is mainly longleaf-slash pine and loblolly-shortleaf pine, with oak-gum-cypress along rivers. The Atlantic Coastal Flatwoods section is 30,215 square miles.

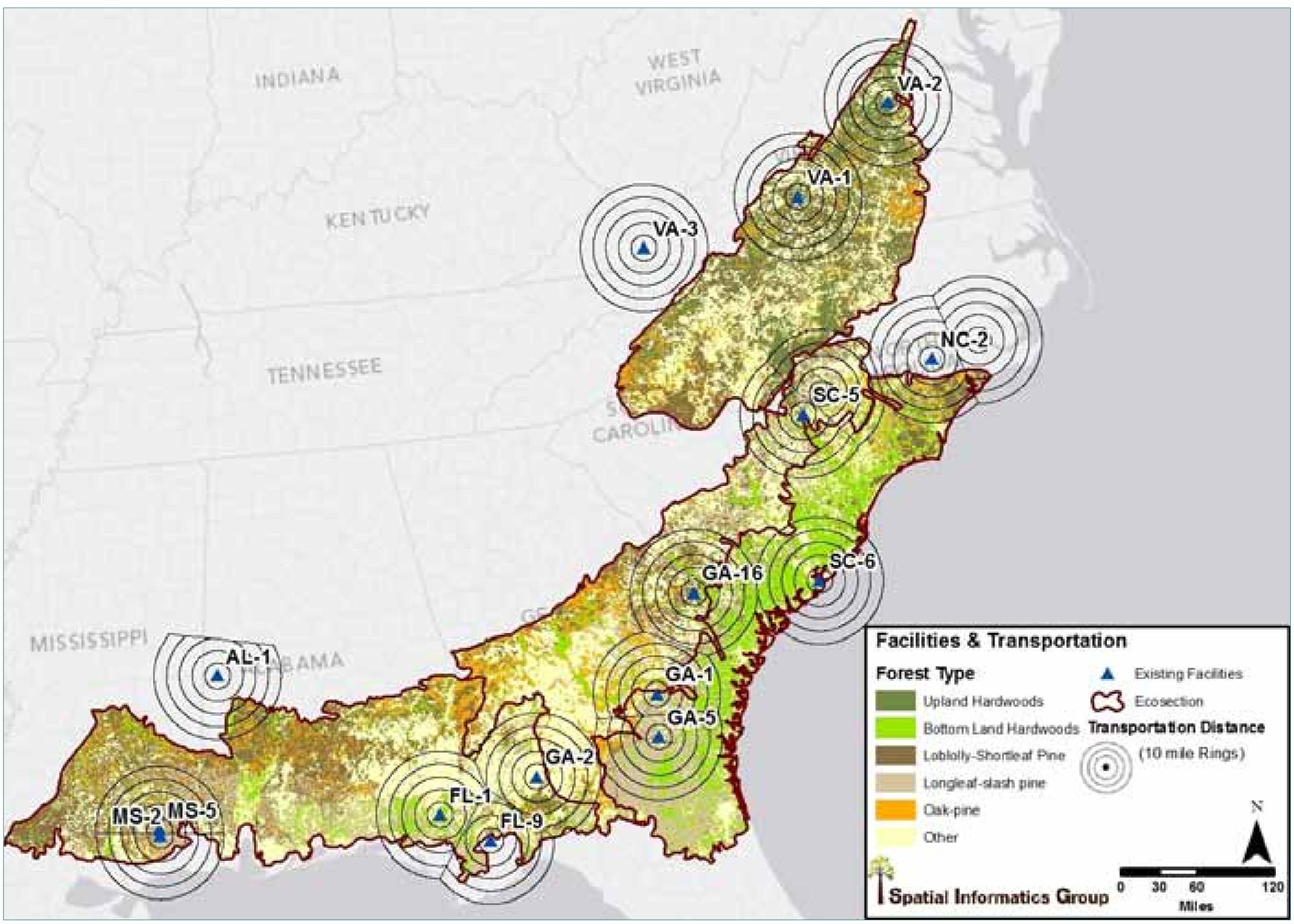
Section 232J-Southern Atlantic Coastal Plains and Flatwoods. This section extends from southern Georgia northeast through central South Carolina and south-central North Carolina. It belongs to the Outer Coastal Plain Mixed Forest Province (232), which "is an eco-region of humid, maritime climate; winters are mild and summers are warm. Precipitation is abundant with rare periods of summer drought. Upland forest vegetation is dominated by conifers, with deciduous hardwoods along major floodplains." This section is weakly dissected irregular or smooth plains. Vegetation is mainly a mixture of loblolly-shortleaf pine, longleaf-slash pine, oak-pine, and oak-gum-cypress cover types. The Southern Atlantic Coastal Plains and Flatwoods section is 31,802 square miles.

Transportation Distance

Existing and proposed facilities data was assembled by the Southern Environmental Law Center (SELC). In order to quantify the biomass supply and transportation emissions to facilities, five concentric transportation rings of 10 miles radius from each facility were constructed. This was done for existing and for existing plus proposed facilities (Figure 10, Figure 11). Wood supply for facilities was modeled using distance to the facilities with equal weight given to each; in other words the distance was equally split between them. Therefore, up to a 50-mile radius was allowed for the wood supply area for a facility unless restricted by neighboring facilities. While this study relies on individual facility data, no attempt was made to characterize the individual facilities, only the aggregate data.

Figure 10.

Existing facilities (17) with transportation rings, showing study area and forest types.



3. ATMOSPHERIC CARBON ANALYSIS *(cont'd)*

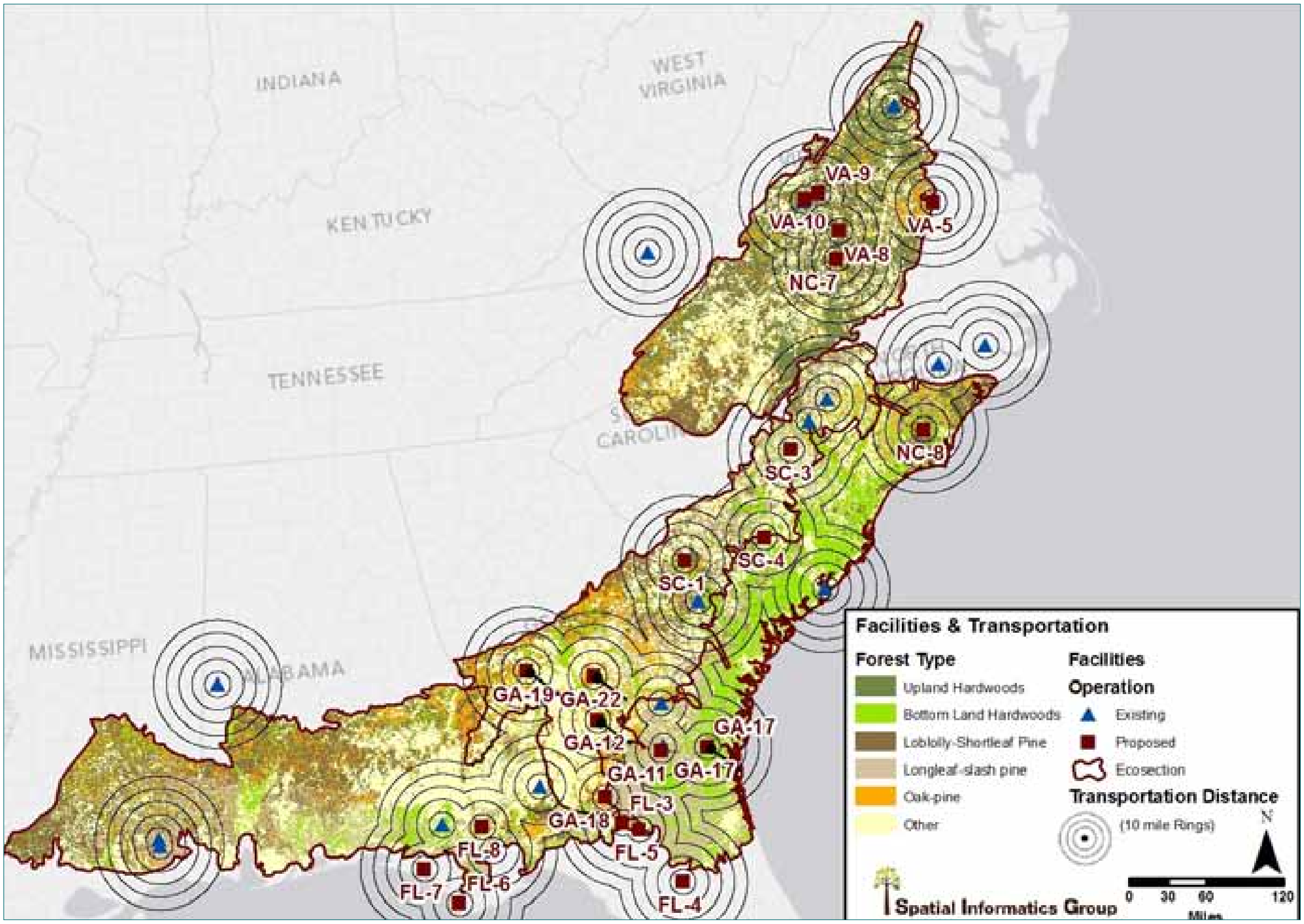


Figure 11.

Existing (17) and proposed (22) facilities with transportation rings, showing study area and forest types. (Some of the points overlap with one another).

Constraints on Forest Management

In order to estimate forest management response to biomass markets so that feedstock supply and subsequent carbon accounting could also be estimated, we identified constraints on forest management applied to private lands in the study area. We considered family forest landowners that would not harvest based on typical economic incentives and physical constraints of the terrain to operations.

The National Woodland Owner's survey results (Butler, 2008) were used to estimate the proportion of the private forested landowners in the study area that would not generally respond to a market by harvesting their lands. Family forests make up 67.4 percent of the private forests and 31 percent do not have a history of harvesting their lands. Therefore we estimate that 20.9 percent of the private forest landscape is in a no-harvest scenario.

Operational Restrictions

Operational acres were those with willing landowner participants and unrestricted access. The acreage required to meet a facilities biomass fiber demand was calculated. The acres remaining after consideration of biomass supply, reserve acres and operationally restricted acres was allocated to the business as usual (BAU). Biomass supply acres were assigned silvicultural prescriptions that incorporated biomass harvesting and BAU acres were assigned baseline silvicultural prescriptions. These prescriptions were assigned by forest-type group so that the appropriate starting inventory was used. Operational restrictions were estimated using FIA data by eco-section and forest-type group (Table 28 below). Restricted acres were defined as those with the following attributes:

- Broken terrain
- Mixed wet and dry soils
- Slopes greater than 40 percent, or
- Water year-round

Table 28. Percent of Operational-Restricted Acres by Eco-Section and Forest-Type Group

Eco-Section	Forest-Type Group	Percent Restricted
231I	Bottom Land Hardwoods	19.5
231I	Upland Hardwoods	3.7
231I	Oak-pine	1.5
231I	Loblolly-shortleaf pine	0.8
232B	Bottom Land Hardwoods	19.6
232B	Upland Hardwoods	2.2
232B	Oak-pine	2.0
232B	Loblolly-shortleaf pine	0.6
232B	Longleaf-slash pine	1.0
232C	Bottom Land Hardwoods	1.0
232C	Upland Hardwoods	1.1
232C	Oak-pine	6.9
232C	Loblolly-shortleaf pine	0.9
232C	Longleaf-slash pine	1.0
232J	Bottom Land Hardwoods	10.7
232J	Upland Hardwoods	1.6
232J	Oak-pine	3.6
232J	Loblolly-shortleaf pine	1.3
232J	Longleaf-slash pine	0.4

3. ATMOSPHERIC CARBON ANALYSIS *(cont'd)*

3.3.2 Definition of Silvicultural Prescriptions for Eco-regions, Forest Types, and Stand Origin

The purpose of this sub-task was to define a BAU baseline for silvicultural practices as they exist today from current on-the-ground activity along with a viable biomass alternative. These silvicultural prescriptions were to be assessed by eco-regions, forest type, stand origin, and ownership type. The Forest Guild took the lead in developing these options based on its extensive in-field networks and sustainable silvicultural expertise.

The Forest Guild set up a local forester input process that assisted with defining the BAU- and biomass-affected silvicultural methods used for the forest types and eco-sections considered in this study. The silvicultural simulations by forest type and eco-section are listed in Tables B-1 to B-3 in Appendix B. Note that prescriptions repeat over time. Also in Appendix B, Table B-4 shows the age distribution for one eco-section, for illustration. A set of no-harvest scenarios was also simulated for each eco-section, stand-origin, and site-class category.

Site productivity was grouped into low and high using the FIA site classes: 1-3 were high and 4-7 were low. Three general prescriptions were modeled:

- Baseline, with a biomass market and with no harvesting
- Baseline harvests cut trees down to 4 inches dbh
- Biomass harvests took trees down to 0 inches dbh

Regeneration harvests may have site preparation and burning simulated. Default Forest Vegetation Simulator, Southern Variant (FVS-SN) values were used for naturally regenerated stands except for longleaf pine, which was broadcast burned. Plantations were 100 percent site prepared. The FVS-SN default values were 20 percent treated mechanically, 5 percent burned, and 75 percent untreated. No differences were assumed in site preparation and burning for the baseline versus the biomass harvests.

These simulations represent plausible depictions and are intended to provide data for comparisons between treatments and fiber utilization scenarios. They are not intended to provide predictions of landscape changes over time, which would require a regional timber supply model.

3.3.3 Inventory Data Preparation

The purpose of this sub-task was to prepare the FIA data for analysis. Two elements need to be investigated when preparing FIA data for analysis—data quality and the issue of regeneration.

Data Quality

The FIA data were extracted from eight state-level databases using the *FiaToFvs utility* (Keyser, 2011), which created FVS-formatted databases. These databases were filtered and combined into four databases corresponding to the four eco-sections. FIA plots, which are 4-plot clusters, were treated as stands composed of four plots. The most recent measurement cycle was used for characterizing current conditions. The previous inventory cycle was used in conjunction with the other data for the growth model evaluation. A common starting year of 2010 was used regardless of the actual measurement year of the plot. The most recent (2010) FIA survey summary was used and relative plot weights were retained. In some cases, age was missing from the FIA plots. Since age was used as a trigger for some silvicultural treatments, random ages were assigned to stands where this occurred.

Each set of plots that were projected under a silvicultural scenario were averaged using the FIA expansion factors. This produced a yield stream that reflected the application of the prescription to the average landscape for a particular eco-section, forest-type group, and site group. The two site groups were then averaged together using their relative representation on the landscape. This averaged yield stream was then used in conjunction with vegetation maps to model carbon dynamics.

Regeneration

Regeneration assumptions are important to long-term forest growth projections. Plantation densities (TPA) were based on expert opinion. Natural stand regeneration was based on FIA data queries. Tables B-5 to B-6 in Appendix B show the regeneration assumptions for two examples of forest types for an eco-section. Data in these tables were derived from FIA plots in trees 0-5 inches dbh. Sprouting species automatically sprout when harvested in FVS-SN, so only non-sprouting species were regenerated from seedlings. Regeneration was input 10 years after harvest, at the sapling/pole stage. Sprouting was set to the following to avoid overstocking the stands, which was observed from the simulations using the defaults.

- If stand density index (SDI) less than 100, use 100 percent of default sprouting model
- If SDI 100 to 200, use 90 percent of default sprouting model
- If SDI 200 to 300, use 80 percent of default sprouting model
- If SDI more than 300, use 70 percent of default sprouting model
- If the quadratic mean diameter (QMD) less than 10 (young stands), use 10 percent of default sprouting model (for pre-commercial thinning)
- If the QMD less than 10 and more than 700 trees per acre, use 1 percent of default sprouting model

This appeared to create a generally stable stocking situation over the simulation period. The no-harvest scenarios did not have regeneration modeled.

3. ATMOSPHERIC CARBON ANALYSIS *(cont'd)*

3.3.4 Forest Modeling

This sub-task focused on quantifying forest biomass dynamics using the above information and standard modeling approaches. Several elements were selected for this analysis, including the data and software used, specifics concerning the growth and yield models, and approaches to evaluating growth. In general, non-merchantable wood (*residuals*) was considered as the first lowest cost supply material, up to the amounts allowed under the sensitivity analysis described below. Clean woodchips from fiber defined as meeting pulp merchantability standards (*pulpwood*) was provided next, also up to the amounts allowed by the sensitivity analysis below. These elements are discussed in detail as follows.

Data and Software

The FIA data (FIA, 2010) was used to develop stand-level data for simulating growth, harvest, and mortality. Eco-section summaries were also queried from the FIA data.

The FVS-SN (version 2/16/2011)(Keyser, 2010), was used for modeling stands. Pine plantations were evaluated using simulations in PTAEDA version 4 (Burkhart et al., 2008), a loblolly-pine plantation model. SUPPOSE (Crookston, 1997) was used for FVS simulations. R statistical software was used for some analysis and graphics (R, 2011). Microsoft Excel was used for data checking, calculations, and graphics. Microsoft Access was used for plot and tree-data storage as well as carbon outputs, which were linked to SUPPOSE software using the database extension (Crookston et al., 2011). The Fia2Fvs utility, available on the FVS website, was used to translate FIA data to an FVS readable Access database.

Growth and Yield Modeling

Non-renewable fuels such as oil, natural gas, and coal do not currently have an operational and economical sequestration component. Forests do naturally remove carbon from the atmosphere, however, and a complete GHG accounting of biomass energy should account for this fact. We considered only private lands for our analysis, which produce 96 percent of the roundwood in the Southeast (Johnson et al., 2009). We modeled forest growth, harvest, and mortality over a 100-year period to understand the long-term GHG implications of supplying biomass.

Each of the five major forest-type groups (Table 27 on page 69) in each of the four eco-sections was modeled under a BAU baseline, with a biomass market and unharvested. This allowed us to construct landscape scenarios that matched generalized landowner responses to available markets. The FIA data (FIA, 2010) were used for the starting conditions.

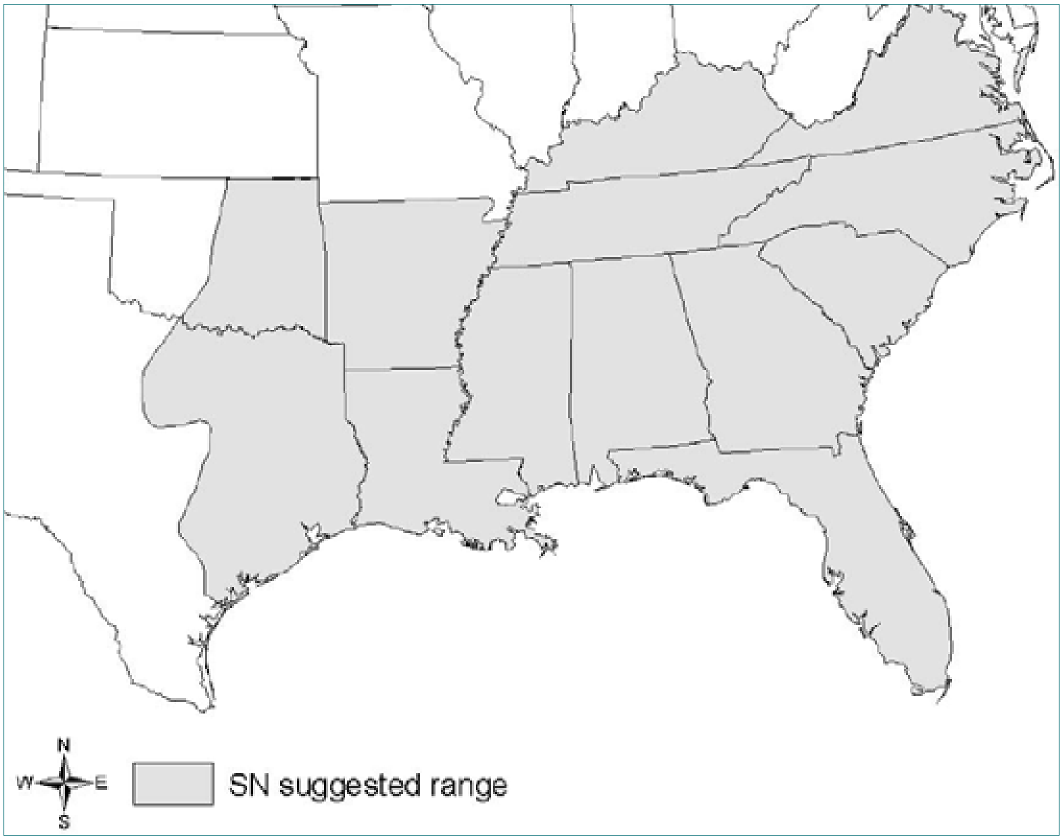


Figure 12.

Geographic range for the southern variant of FVS. From Keyser (2010).

The FIA databases for each state in our study area were downloaded from the FIA website. Data were queried from the databases to create tree lists for growth simulation. Tree-list queries were constructed for private lands by age, site productivity, stocking, eco-section, and forest type. Within each category, a random sample of plots was taken for the purposes of modeling. At least 250 plots were modeled for each category, when available, so that landscape variation was represented without unnecessary redundancy in data. Regional forest-characterization queries were conducted to ensure FIA data matched with GIS vegetation coverages.

Age class distributions were examined, by category, to characterize starting conditions. Where ages were missing, they were randomly allocated since age was a parameter used for some silvicultural treatments.

FVS-SN (Figure 12 above) was used to model all simulations for 100 years in 5-year increments. Harvests in the no-biomass-harvest baseline scenarios assumed that all non-merchantable wood fiber was left in the woods. Harvests in the biomass scenarios assumed that a minimum of 10 percent of the non-merchantable wood fiber was left in the woods; this assumption allows for 10 percent being a minimum so that between 10-100 percent of non-merchantable wood fiber may be allocated to biomass pools. This amount was varied for the sensitivity analysis.

3. ATMOSPHERIC CARBON ANALYSIS *(cont'd)*

The merchantability standards used were the FVS-SN defaults shown in Table 29 below. Other default specifications used in modeling are shown in Table 30 at the bottom of the page. A minimum harvest level of 1,000 cubic feet per acre of merchantable wood fiber was specified for commercial thins, to avoid un-economical harvest simulations.

Table 29. Merchantability Standards from FVS-SN

Pulpwood Volume Specifications		
Minimum DBH/Top Diameter Inside Bark	**Hardwoods**	**Softwoods**
All locations codes	4.0 / 4.0 inches	1.0 / 1.0 inches
Stump Height	**1.0 foot**	**1.0 foot**
Sawtimber Volume Specifications		
Minimum DBH/Top Diameter Inside Bark	**Hardwoods**	**Softwoods**
All location codes	12.0 / 9.0 inches	10.0 / 7.0 inches
Stump Height	**1.0 foot**	**1.0 foot**

Source: Keyser (2010)

Table 30. Default Parameters Used in FVS-SN

	Eco-Section			
Parameter	**Central Appalachian Piedmont (231I)**	**Atlantic Coastal Flatwoods (232C)**	**Southern Atlantic Coastal Plains and Flatwoods (232J)**	**Gulf Coastal Plains and Flatwoods (232B)**
Location Code	81110	81201	81201	80103
Ecol. Unit Code (EUC)	232BIC	232CA	232JA	232BI

Carbon storage from onsite forest pools and long-term storage in wood products and landfills was estimated. Production from residual fiber and wood meeting pulpwood merchantable standards was estimated. The yield streams were annualized to match the demand units for the facilities.

The yields from each forest type were averaged across natural and plantation origin based on the relative abundance of each in each eco-section (see Table 31 below). Harvest of non-merchantable wood was set to a maximum removal of 90 percent for biomass harvesting.

Table 31. Acres of Plantations by Eco-Sections and Forest Type Groups

Eco-Section	Forest Type	Acres	Acres in Plantation	Percent in Plantation
231I	Loblolly-shortleaf pine	4,946,320	2,720,149	55.0%
232B	Loblolly-shortleaf pine	6,810,148	4,082,053	59.9%
232B	Longleaf-slash pine	4,608,327	2,222,395	48.2%
232B	Oak-pine	2,900,973	568,323	19.6%
232C	Loblolly-shortleaf pine	1,891,406	1,047,443	55.4%
232C	Longleaf-slash pine	5,152,756	3,276,062	63.6%
232J	Loblolly-shortleaf pine	3,074,770	1,829,583	59.5%
232J	Longleaf-slash pine	2,685,180	1,447,152	53.9%
Total		32,069,879	17,193,160	53.6%

Source: FIA

3. ATMOSPHERIC CARBON ANALYSIS *(cont'd)*

The simulations projected individual FIA clusters under a variety of silviculture. Even-aged management was simulated in all but the upland hardwood stands where selection management was simulated (Appendix B). An example showing the initial harvest, regeneration, pre-commercial thin, mortality over time, and clearcut cycle is shown in Figure 13 below.

Figures 14 and 15 on the next page show examples of the averaged yields of stored CO_2e for two specific eco-section and forest type combinations. In general, the biomass prescriptions had lower stored carbon than the no-biomass harvest prescriptions. The no-harvest prescriptions generally stored substantially more carbon than the two-harvest scenarios. These results provided inputs to the landscape analysis. There could be significant atmospheric benefits if the landscape were converted to a no-harvest scenario where leakage was limited and alternative energy had a small carbon footprint. This is a scenario that we are currently not experiencing, but there are major initiatives underway to explore the possibilities. The landscape-level no-harvest scenario was not included in our modeling or results.

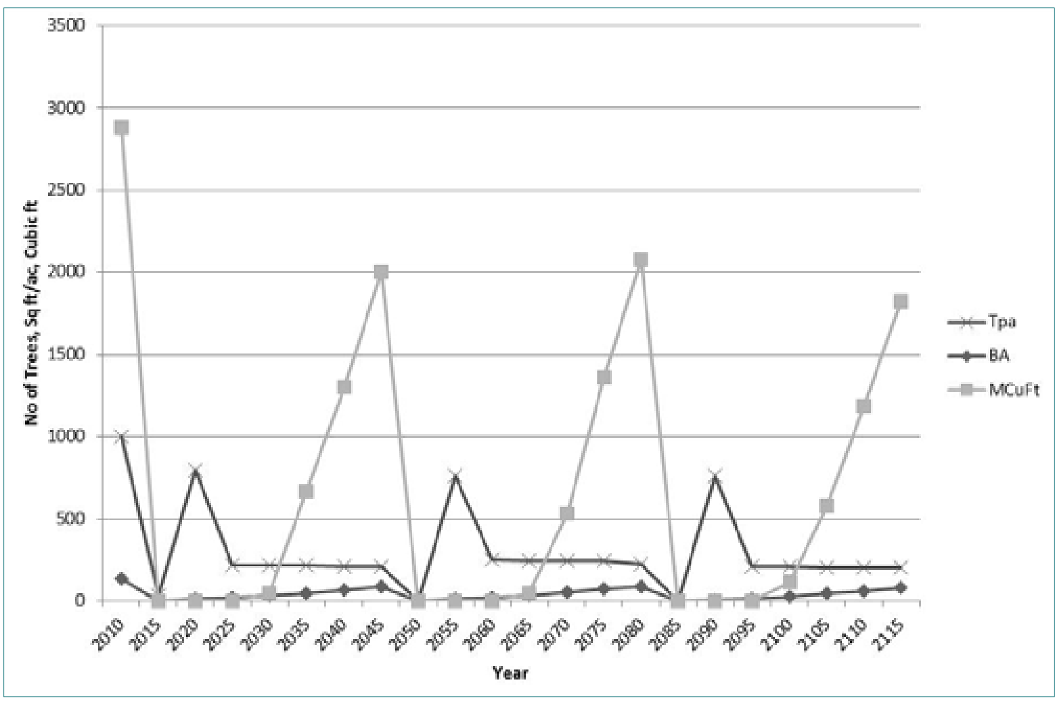


Figure 13.

An example of a plot cluster projection.

This is for a 47-yr old loblolly pine plantation in eco-section 231I, low site, with biomass harvest. A pre-commercial thin occurs early in the rotation, which is seen in the drop in trees per acre (TPA). The basal area (BA) and merchantable cubic foot volume (MCuFt) increase over each 35-year rotation. Slight variations are seen in each rotation due to FVS stochasticity and changes in sprouting species.

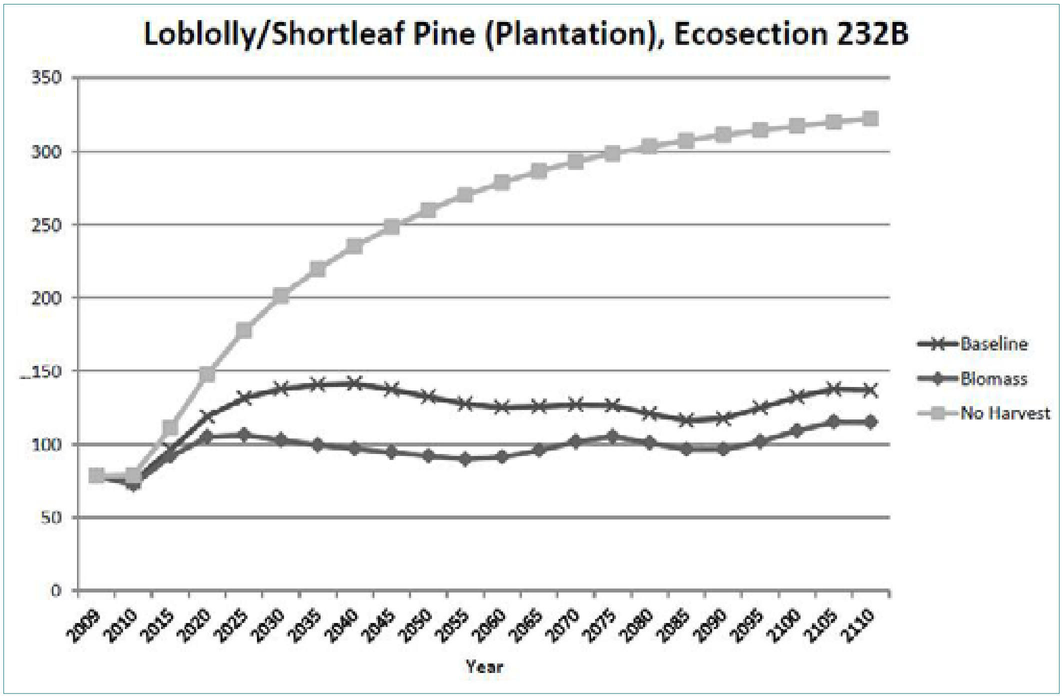


Figure 14.

Averaged projections of carbon storage in the forest and wood products (in-use and landfills) for naturally regenerated loblolly-slash pine in eco-section 231B (Gulf Coastal Plains and Flatwoods) using three silvicultural prescriptions.

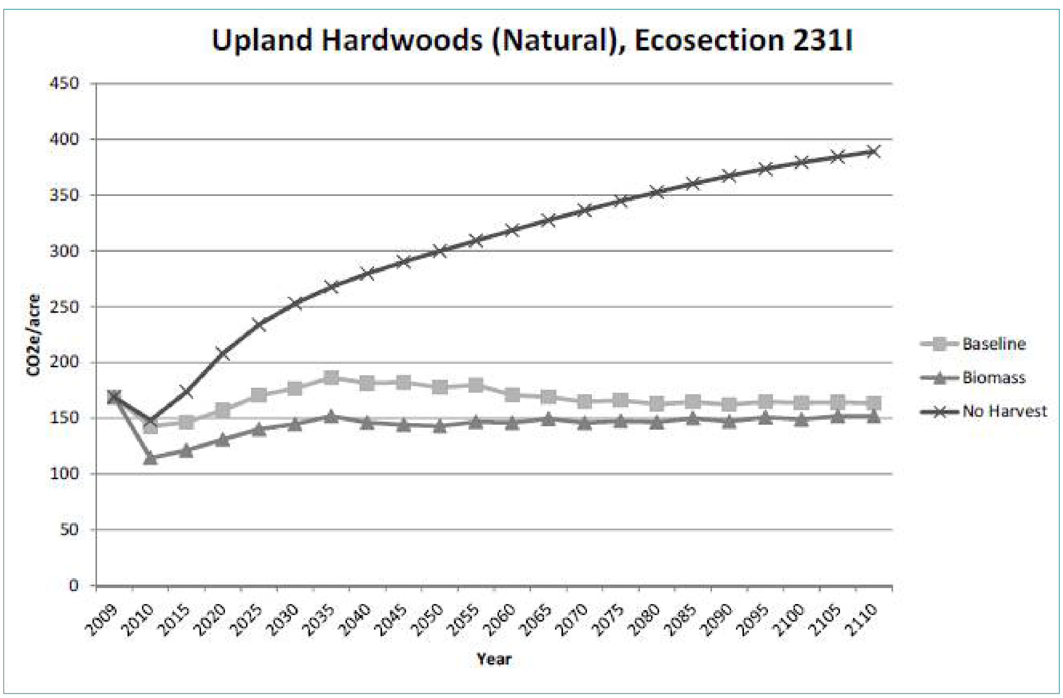


Figure 15.

Averaged projections of carbon storage in the forest and wood products (in-use and landfills) for naturally regenerated upland hardwoods in eco-section 231I (Central Appalachian Piedmont) using three silvicultural prescriptions.

3. ATMOSPHERIC CARBON ANALYSIS *(cont'd)*

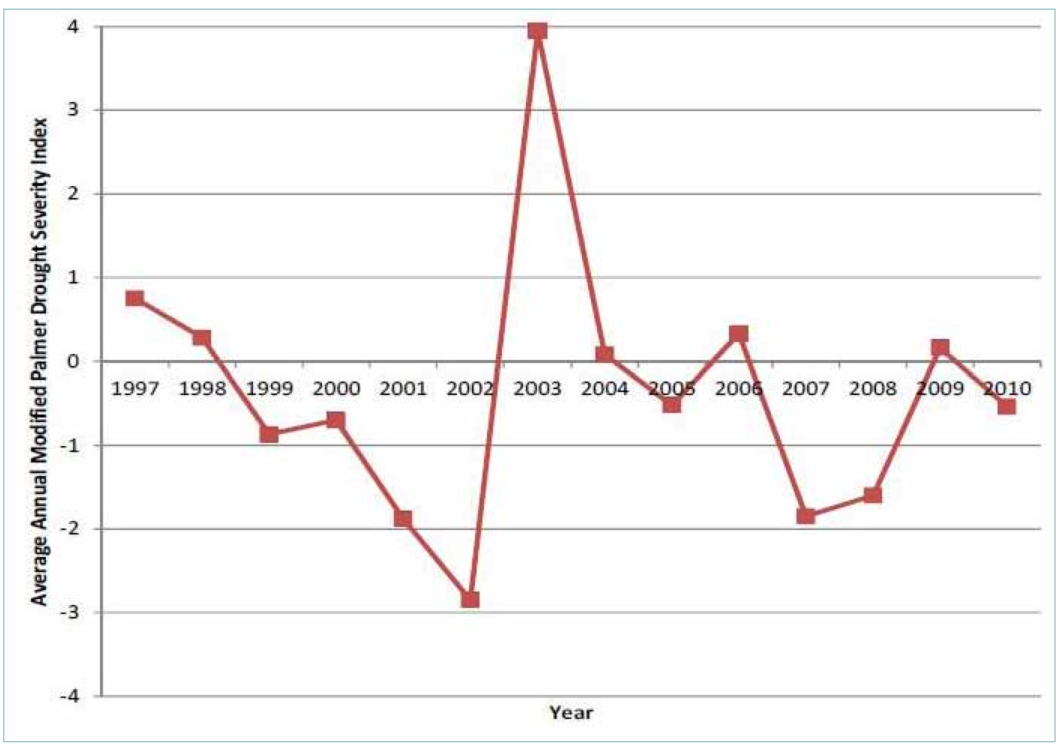
Growth Evaluations

The Southern variant of FVS covers a large geographic region, which may contain deviations from projected average growth locally or regionally. To account for possible bias, the model was evaluated for one of the eco-sections for 5-year bias in above-ground live tree carbon. FIA plots that had been re-measured using the annual inventory method were projected using the FVS carbon model (Rebain, 2010; Jenkins et al., 2003 biomass equations). Plots that had treatments were excluded. The annualized changes in carbon were compared and the model was found to overestimate by almost 60 percent. The period of growth was marked by generally dry-to-drought conditions (see Figure 16 below) however, which makes generalizing conclusions difficult without a longer-time series of data. The FVS functions were fit to data from previous time periods, which were likely nearer normal. The other eco-sections were not examined as the entire Southeast experienced similar climate during this period.

Figure 16.

Average annual modified Palmer Drought Severity Index for the North Carolina Piedmont region.

Palmer classifications are: -4 to -3 severe drought, -3 to -2 moderate, -2 to -1 mild, -1 to 1 dry to normal to wet, >1 wet.



Source: State Climate Office of North Carolina website (www.nc-climate.ncsu.edu)

An additional evaluation was conducted by comparing Loblolly plantation projections of FVS-SN with the projections from the Loblolly plantation model PTAEDA version 4 (Burkhart et al., 2008). Table 32 below shows the results of this comparison. While there were larger deviations for the harvested volumes, total yields were 10-12 percent for the entire rotation. This was felt to be an adequate level of accuracy for a regional analysis.

Finally, overall projections of per-acre yields were subjectively compared to regional averages (McClure and Knight, 1984) and found to be reasonable. This was done for each of the major forest types.

Table 32. Comparison of Simulations Using Non-Biomass Prescriptions for FVS-SN and PTAEDA Version 4

		Ending		Harvest	Total Yield	
Simulator	**Site**	**BA**	**Volume (ft^3/ac)**	**Volume (ft^3/ac)**	**Volume (ft^3/ac)**	**Difference (%)**
FVS-SN	Low	108	2,829	4,113	6,942	10%
PTAEDA		90	3,525	2,740	6,264	
FVS-SN	High	112	3,389	4,616	8,005	12%
PTAEDA		93	3,729	3,345	7,074	

3. ATMOSPHERIC CARBON ANALYSIS *(cont'd)*

3.3.5 Carbon Accounting

The focus of this sub-task was to quantify the GHG implications of different technology types and fuels sources for producing energy in the Southeast. This information will be used to gain a better understanding of the implications for potential energy policy and markets on climate change. This sub-task specifically tracks the fuel production and transportation emissions, facility emissions, and forest carbon dynamics for the region. We analyzed stand-alone electric power and electric-led CHP technology pathways; thermal-led energy pathways were not examined. Carbon yields over time from the forest, harvesting, transportation, and facilities emissions were combined in an Access database where queries were used to produce analysis datasets. These datasets were then read into an Excel spreadsheet for final analysis. Below is a detailed description of the major elements associated with this sub-task.

Major Assumptions

The biomass carbon accounting included the onsite forest pools of above- and below-ground live trees, standing dead wood, and down dead wood. Storage of wood products in in-use and landfill pools was also included. Harvest emissions were estimated using a factor of 0.015 tonnes of CO_2 per bone dry ton (BDT) of material produced. This assumed 16.65 lbs. CO_2 per green ton (Manomet, 2010). Truck transportation emissions were estimated using a factor of 0.000134 tonnes of CO_2 per BDT-mile, which assumed 12.5 tons per truck, 6 miles per gallon and 22.2 lbs. CO_2 per gallon of diesel fuel (EPA, 2005). The miles transported were estimated using the center radius of the transportation rings. Pellet mills were assumed to export 90 percent of their material to northern Europe; an emissions factor of .262 tonnes CO_2 per BDT was assumed for shipping (Henningsen et al., 2000). This was varied for the sensitivity analysis.

Biomass Facilities

Existing and proposed facilities data were assembled by the Southern Environmental Law Center (SELC, 2011). It should be noted that the number of proposed facilities is growing and has grown after the initial data were used as input, including a 75 MW co-gen plant consuming 870,000 tons per year in Covington, Virginia and a new 400,000 ton per year pellet plant in Northampton County, North Carolina.

Each of these facilities had information regarding type of power/fuel, location, status, anticipated supply sources, and capacity. Note that proposed facilities included existing facilities that are closed but may re-open. This analysis assumed that it takes a supply of 6,868 BDT per year per MW for older biomass facilities and 6,244 BDT per year per MW for new biomass facilities (see Appendix A). Biofuel facilities were not considered in this analysis due to their current relatively small impact and uncertain near-term growth.

Biomass Supply and Transportation Emissions

In order to quantify the biomass supply and transportation emissions to facilities, five concentric transportation rings of 10 miles radius from each facility were constructed. This was done for existing and for existing plus proposed facilities (See Figures 10 and

11 on pages 71 and 72). Wood supply for facilities was modeled using distance to the facilities with equal weight given to each; in other words, the distance was equally split between them. Therefore, up to a 50-mile radius was allowed for the wood supply area for a facility unless restricted by neighboring facilities. In practice, there is a lot of overlap in the woodsheds of the proposed facilities. The methodology used in this study was designed to give a conservative estimate of regional transportation emissions by pushing the biomass to the nearest facility.

Source of Supply

Pellet mills were assumed to use only clean chips from merchantable logs that would otherwise be categorized as pulpwood, although not necessarily sold as such as this is determined by local markets. Otherwise, for power plants and CHP, supply was assumed to first be filled by non-merchantable material (residuals) including tops of boles, small trees, and crown branches. If supply was not met by residual material, then wood that met pulpwood merchantable standards was used. Sawtimber was assumed to not be available as biomass feedstock.

Technology Pathways and Facility Emissions

An analysis of the GHG accounting related to biomass energy production may be considered as a function of both the fuel and technology used. We examined 11 technology pathways that varied based on fuel and the kind of energy that was produced. These pathways were selected to represent a likely suite of possible scenarios to be found in the Southeast either currently or in the future and consequently included standalone electric power generation and electric-led CHP technologies. Appendix A lists the 11 technology pathways examined along with the attributes of each.

Facility emissions were based on their associated technology pathways. Pellets were assumed to be used in facilities having new energy production from wood pathways (Pathway #2A). Almost all pellets were consumed in European facilities. Emissions were estimated by multiplying the amount of fuel used by a ratio of CO_2 produced per unit of fuel burned. The ratio of CO_2 produced per unit of biomass fuel burned was estimated to be 1:87.

Common Geographic Boundaries

The forested area was defined to be the area of the four eco-sections that included the existing and proposed facility woodsheds, which were defined by a 50-mile radius. By having a common geographic area, the two scenarios of existing facilities and full build out of proposed and existing facilities could be compared. The acreage of proposed facility woodsheds was assigned the baseline no-biomass harvest silviculture when analyzed using existing facilities only. The new facilities would then increase biomass use within the defined landscape.

Pro-Rating Facilities Boundaries

Facilities outside the four eco-sections in the study were included when their 50-mile wood supply radius overlapped with the study area. The wood fiber demand was pro-rated based on the amount of supply area in the study area relative to the entire terrestrial supply area for a facility. Demand for each facility was also adjusted by the amount of supply estimated to be taken from the forest as opposed to wood waste from mills and other sources.

3. ATMOSPHERIC CARBON ANALYSIS *(cont'd)*

Common Non-Harvested Lands

The sequestration of carbon by non-harvested lands (20.9 percent) did not contribute to the facility-based analysis since it was the same in both the current and full build-out scenarios. The woodsheds of facilities that were partially in the study area were pro-rated based on their acres in the study area relative to their total acreage.

Temporal Period

Annual GHG emissions and forest carbon dynamics were tracked over 100 years on an annual and cumulative basis. In addition to the technology pathways defined by the list of facilities we used, we also considered the GHG implications of producing equivalent electricity or thermal energy using all the non-wood biomass technology pathways.

Forest Carbon Pools

Forest carbon pools that were tracked under the baseline and treatment scenarios included live tree above and below ground, standing dead above and below ground, lying dead wood, and wood products storage in in-use and landfill pools. The carbon submodel of the FVS-FFE extension (Rebain, 2010) was used for carbon estimates in live trees and dead wood. The set of allometric equations from Jenkins et al. (2003) were used for live tree biomass estimates, above and below ground. FVS-FFE can use the Jenkins equations, which rely on species and dbh, down to a 1-inch dbh tree. Below 1-inch is interpolated. Wood density, which varies by species, is multiplied by the volume to get biomass estimates. Below-ground dead biomass occurs when trees die or are harvested. FVS-FFE uses a default root decay of 0.0425, which is what we used. Aboveground dead biomass used the FVS-FFE functions.

Wood Products Storage Pools

Wood products storage pools were estimated from the DOE 1605(b) guidelines (DOE, 2007). This was implemented in FVS-FFE based on the 2002 regional estimates (Adams et al., 2006) from Smith et al. (2006). Harvested trees less than 9 inches dbh for softwood and 11 inches dbh for hardwood were assumed to be in the pulpwood merchandising category; larger trees were assumed to be used as sawlogs. The age classes of the wood products pools for in-use and landfill were tracked by FVS-FFE with age 0 at the beginning of the 5-year period where harvest was simulated. Two other wood product pools were available—the emitted with energy capture and emitted without energy capture—but these were ignored for this analysis since this data feeds into an energy-use analysis.

Carbon Pools NOT Tracked

The soil, forest floor, and understory vegetation were not tracked due to the expectation that there would not be significant changes in these pools between the scenarios (Gershenson et al., 2011) and because of the lack of accurate prediction models.

Estimating Carbon Stock Changes

Changes in carbon stocks over time were used to estimate GHG flux between the biosphere and atmosphere. Biomass was converted to carbon by multiplying by 0.5 (Penman et al., 2003; Rebain, 2010). Carbon was converted to CO_2 equivalence (CO_2e) by multiplying carbon estimates by 3.67, which is the ratio of the atomic weights. CO_2e was reported in metric tons (tonnes) per acre or in total tonnes. All results were reported in CO_2e.

Estimating Methane Production

Methane production from slash burning was estimated using the CO_2 emitted from the biomass burned multiplied by a factor of 0.07 (CDM 2011; IPCC 2006) increasing the emissions by 7 percent. Methane production from decomposition of dead wood in the forest was assumed to be negligible (e.g., IPCC, 2006).

3.3.6 Sensitivity Analysis

A model, including the parameters indicated above, was constructed to analyze the GHG consequences of two different levels of biomass utilization and power production in the Southeast. To help examine the effects of varying different potential market and policy actions, the model was designed to manipulate four different parameters. These parameters were set to default settings for the basic analysis of the two scenarios. Then the parameters were altered to see if they resulted in significant changes to the atmospheric carbon profiles of the two scenarios and to answer the specific questions asked of the study. The following four factors were used for the basic sensitivity analysis:

- ***Wood Supply Directly from the Forest (Forest Supply).*** Some existing and proposed facilities receive 100 percent of their biomass supply either from the forest or from non-forest sources such as mill residues or urban tree trimmings. Some facilities, however, claim a variable amount of their supply directly from the forest; for those facilities we varied the forest supply by setting it at 20 percent, 50 percent, and 80 percent.
- ***Wood Supply from Pulpwood (Pulp Supply).*** Where appropriate (non-pellet mills), residuals were used to fulfill biomass demand first and pulpwood was used when needed. Given that competition may exist for pulpwood for use as pulp and paper, we set limits on the availability of pulp at 0 percent, 50 percent, and 100 percent. For example, a 0 percent from pulpwood would mean that there is no pulpwood allowed in the system for biomass utilization and more residuals would have to be produced.
- ***Wood Supply from Residuals (Non-Merchantable Supply).*** There are physical, economic, and Best Management Practices (BMP) limits to how much of the residuals (non-merchantable wood, bark, foliage) can be removed from the forest. We examine the implications of this by setting the amount of residual removal at 30 percent and 60 percent.
- ***Export of Wood Pellets (Pellet Exports).*** to northern Europe was set at 90 percent and 40 percent.
- ***Efficiency of Biomass Utilization.*** Examined a higher biomass requirement per MW-year of power produced, which was 8,234 BDTs per year per MW for older less-efficient biomass facilities and 6,868 BDTs per year per MW for newer, more-efficient biomass facilities. This specific parameter was examined in its own separate analysis and was not included in all combinations of the general set of 4 parameters described above.

The sensitivity analysis was run using multiple scenarios that allowed the research team to test individual parameters. The scenarios, parameters, and their values were developed using a collaborative process that took into consideration local knowledge, field data, and existing literature. All results are reported for existing facilities and proposed facilities across the entire study area. A list of the simulations used can be found in Table 33 on the following page.

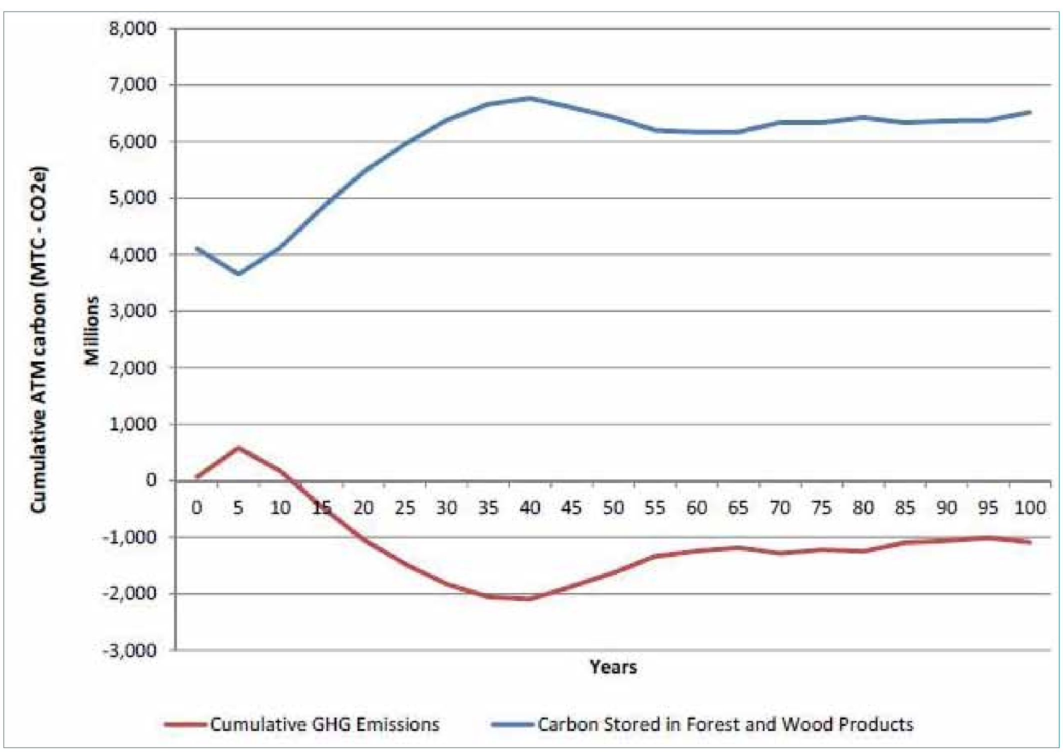
3. ATMOSPHERIC CARBON ANALYSIS *(cont'd)*

Table 33. Summary of Sensitivity Analysis Scenario Development (percent)

Scenario	Efficiency (BDTs/MW-yr)	FA: Forest Supply	PS: Pulp Supply	NM: Non-Merchantable Supply	EP: Pellet Exports
Default	**6868 old/6,244 new**	**50**	**50**	**60**	**90**
Forest Supply Min.	6868 old/6,244 new	**20**	50	60	90
Forest Supply Max.	6868 old/6,244 new	**80**	50	60	90
Pulp Min.	6868 old/6,244 new	50	**0**	60	90
Pulp Max.	6868 old/6,244 new	50	**100**	60	90
NonMerch Min.	6868 old/6,244 new	50	50	**30**	90
Pellet Export Min.	6868 old/6,244 new	50	50	60	**40**
Facility Efficiency	**6868 high/8000 Low**	50	50	60	90

Figure 17.

Cumulative atmospheric carbon balance of existing facilities over time (lower line) and carbon stored in the forest, in-use wood products, and landfills (upper line).



3.4.0 FINDINGS

In order to understand the implications of market and policy drivers in the development and expansion of a biomass electric power market in the Southeast, we analyzed the current condition and a scenario adding 22 additional biomass power plants to represent the proposed expansion of the biomass power sector in the Southeast over the next few years. A study of actual (and proposed) facilities in the context of the forested landscape and fiber supply area provided a more realistic analysis than a hypothetical comparative analysis. This analysis produced several key findings based on the questions defined above.

The 22 facilities selected for this simulation are all proposed for the next few years and there is the likely possibility that there will be more facilities planned, in addition to the 22, over a longer time period. Findings are presented in this report using the following format:

- **Question.** Define key policy question
- **Result.** Describe the key result from the analysis
- **Explanation.** Describe how the model and sensitivity tools were used to answer the question and discuss key findings

1. What are the atmospheric carbon implications of operating the existing 17 biomass power plants in the study region versus not running them into the future and using fossil fuel instead?

Result. Our findings indicate that the existing biomass facilities examined were generally producing improved atmospheric carbon balance relative to fossil fuels and technologies to provide equivalent power at the regional scale. The macro-patterns remained the same for all the sensitivity-level combinations, including Wood Supply Directly from the Forest (Forest Supply), Wood Supply from Pulpwood (Pulp Supply), Wood Supply from Residuals (Non-Merchantable Supply), and Export of Wood Pellets (Pellet Exports). This would suggest that continuing to run these existing biomass power plants as they are currently sized and scaled today would result in lower atmospheric carbon in the short and long term than shutting them down and shifting to fossil fuels.

Explanation. There were 17 existing biomass electric power facilities (producing 159 MW and 1,775,000 tons of pellets) identified in the study area. The GHG profile produced was a function of the modeling of forest growth, harvest, and mortality; facility emissions based on identified technology pathways; and transportation and extraction emissions. We first present the atmospheric carbon balance for the existing facility landbase, without consideration of proposed facilities. The difference between the carbon storage using biomass harvests and baseline harvests without biomass is incorporated into the profile.

The cumulative atmospheric carbon balance is shown in the lower line in Figure 17 on the previous page. The shape of the cumulative emissions incorporates and is driven by the carbon storage factor, which is illustrated in the top line of Figure 17. The specific nuances of the curves are a function of modeling assumptions and harvest scheduling; the trend of the lines over time is primarily of interest.

3. ATMOSPHERIC CARBON ANALYSIS *(cont'd)*

Figure 18 on the following page shows the cumulative carbon balance comparison of the existing biomass energy facilities (red line in Figure 17) compared to other possible means to meet the same energy demand. Emissions are occurring as harvests are initiated, which is the positive "bump" in the beginning of the line. After the initial emissions, the biomass scenario generally emits less carbon to the atmosphere than the other fuels and pathways. The specific shape of the curve is largely driven by modeling parameters; we are interested in the general trends.

In order to compare the effects of building the proposed biomass facilities, we need to consider the effects on the forested acres impacted by those new facilities. When only existing facilities are in place, those acres outside existing facility woodsheds, but destined to be included in the acreage of the proposed facility woodsheds, were modeled using a business-as-usual (BAU) harvesting scenario that did not include biomass harvesting.

The difference in the carbon balance between the two land bases is illustrated in Figure 19 on page 92. The larger land base sequesters more carbon because the additional acres are sequestering more carbon and are not being biomass harvested. This full land-base analysis will be needed when calculating the effects of the full build-out. This allows us to factor in those acres that are not currently being harvested for biomass utilization in the BAU.

Sensitivity Analysis of Running Existing Facilities

We tested whether the atmospheric carbon balance of the existing biomass facilities relative to the other pathways can be changed by altering the assumptions. When the parameters for the four other assumptions are varied, no significant change in carbon balance was identified (Figure 20). The macro pattern, however, compared to fossil fuel type remains the same for all scenarios modeled (they were all beneficial).

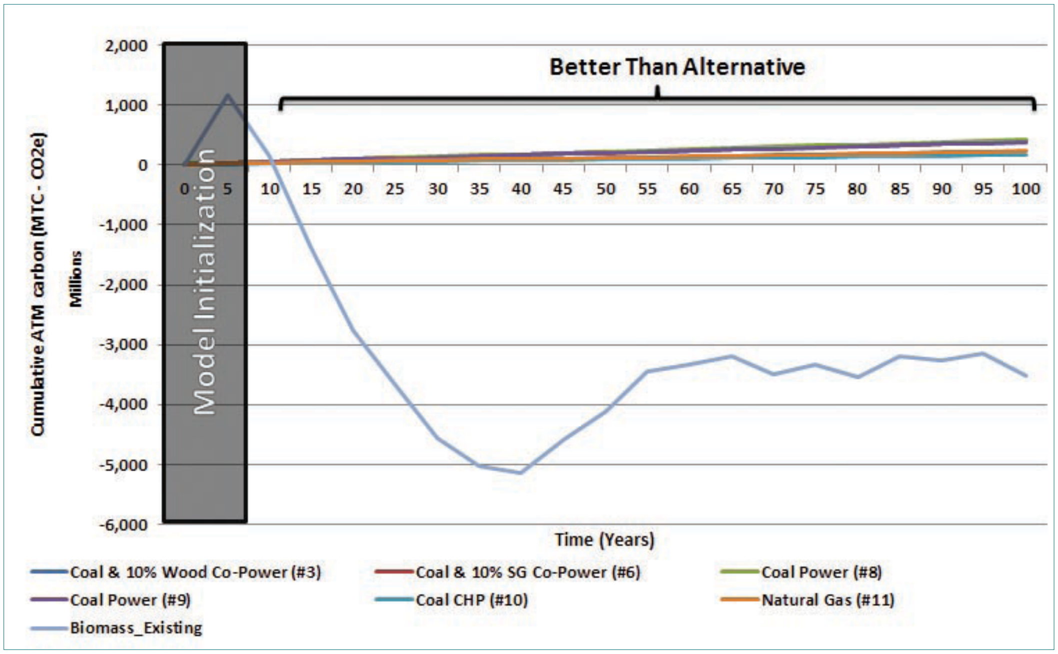


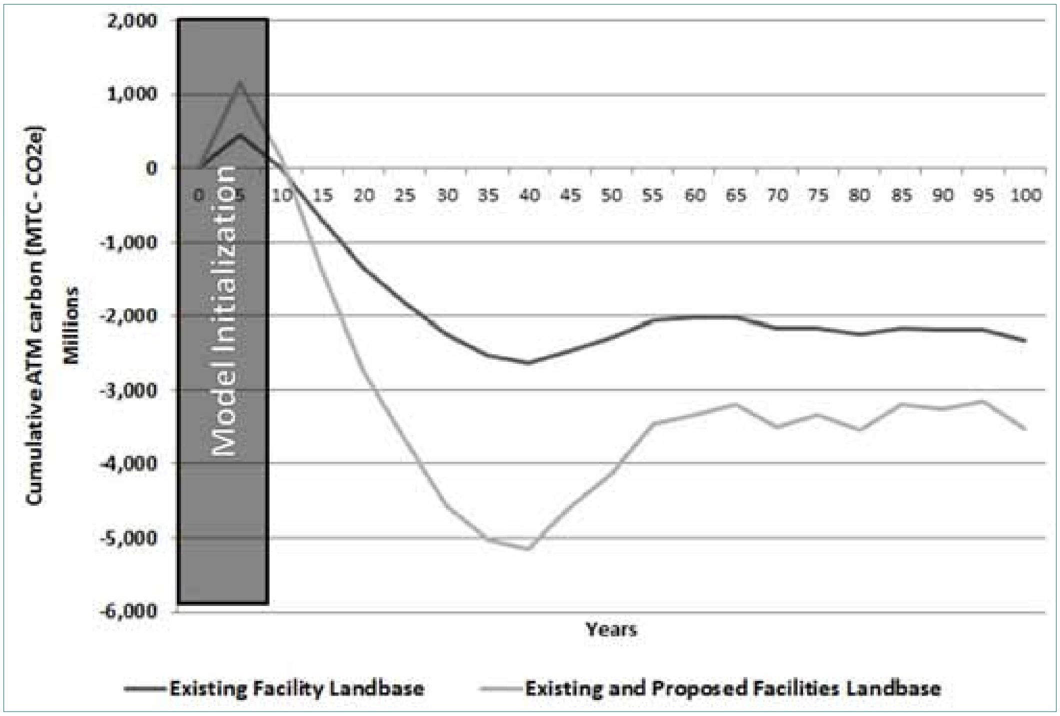
Figure 18.

Cumulative carbon balance of existing biomass facilities with other pathways for comparison.

3. ATMOSPHERIC CARBON ANALYSIS *(cont'd)*

Figure 19.

Comparison of the carbon balance for the existing biomass facilities considering different forested land bases: the wood-sheds of the existing biomass facilities versus the full build-out acres.



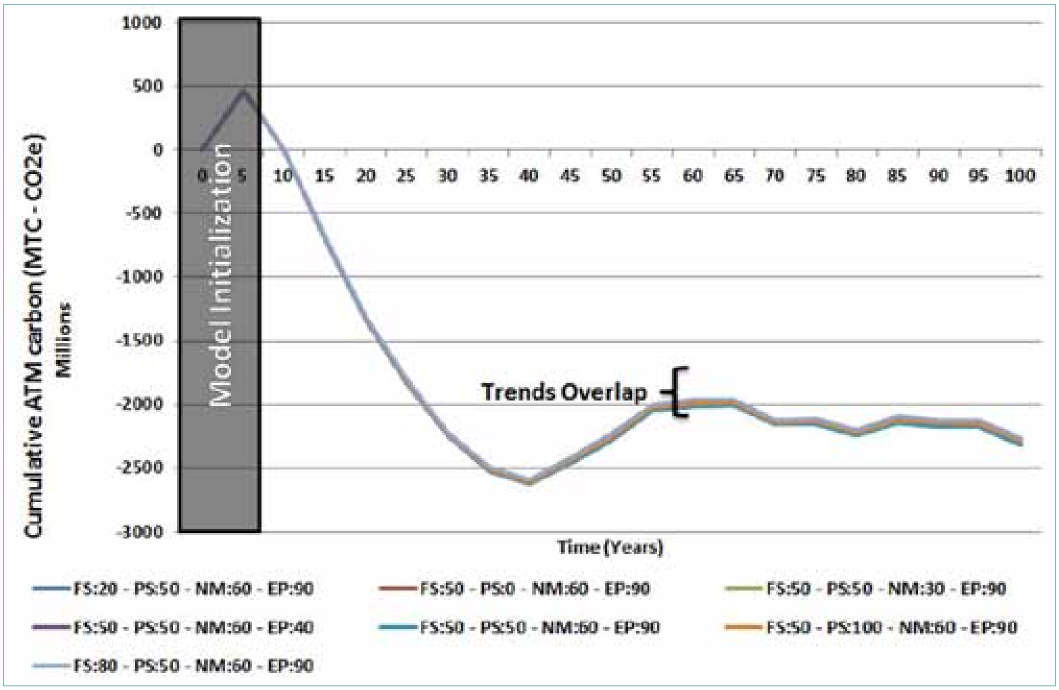


Figure 20.

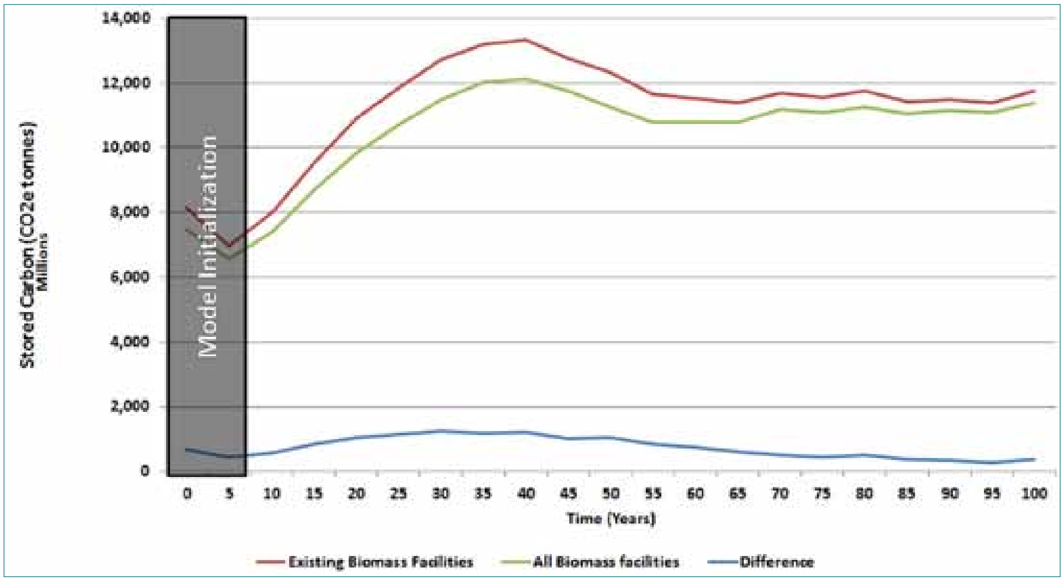
Sensitivity Analysis Conducted for Existing Biomass Facilities.

Results are presented in the following order: Wood Supply Directly from the Forest (FS: Forest Supply) at 20, 50, and 80 percent, Wood Supply from Pulpwood (PS: Pulp Supply) at 0, 50, and 100 percent, Wood Supply from Residuals (NM: Non-Merchantable Supply) at 30 and 60 percent, and Export of Wood Pellets (EP:Pellet Exports) at 40 and 90 percent. The table is keyed in the following format: Forest-Pulp-NonMerch-Pellet. The lines overlap showing that there is no difference between them from a cumulative atmospheric carbon point of view.

3. ATMOSPHERIC CARBON ANALYSIS *(cont'd)*

Figure 21.

Forest and long-term carbon storage (wood products and landfill) for the existing biomass facilities, full build-out of proposed biomass facilities and existing facilities, and the difference between the two (proposed facilities).



2. What are the atmospheric carbon implications of operating the existing biomass power plants as compared to operating these existing plants plus 22 new proposed biomass power plants?

Result. Additional biomass facilities had reduced long-term atmospheric carbon relative to other fuels and technology pathways at a short-term atmospheric carbon cost. The biomass option recovered the carbon debt in 35-50 years depending on the fossil fuel scenarios being compared. The macro-patterns remained almost the same for all the sensitivity-level combinations, including Wood Supply Directly from the Forest (Forest Supply), Wood Supply from Pulpwood (Pulp Supply), Wood Supply from Residuals (Non-Merchantable Supply), and Export of Wood Pellets (Pellet Exports). The results were sensitive to biomass efficiency.

Explanation. We identified a total of 39 facilities, 17 existing, and 22 proposed facilities. The additional 22 biomass power facilities represented 1,014 megawatts of electricity and 3,050,000 tons of pellets. Actual information from facility applications and other public sources, as compiled by SELC (2011), was used to represent the proposed expansion of the biomass electric generating sector in the Southeast over the next several years. The proposed facilities increased demand for wood fiber by 5.2-6.3 million tons a year depending on assumed biomass operational efficiencies (see next section).

We examined the GHG implications of meeting the increased demand using the proposed biomass facilities and compared that to coal and natural gas technology pathways.

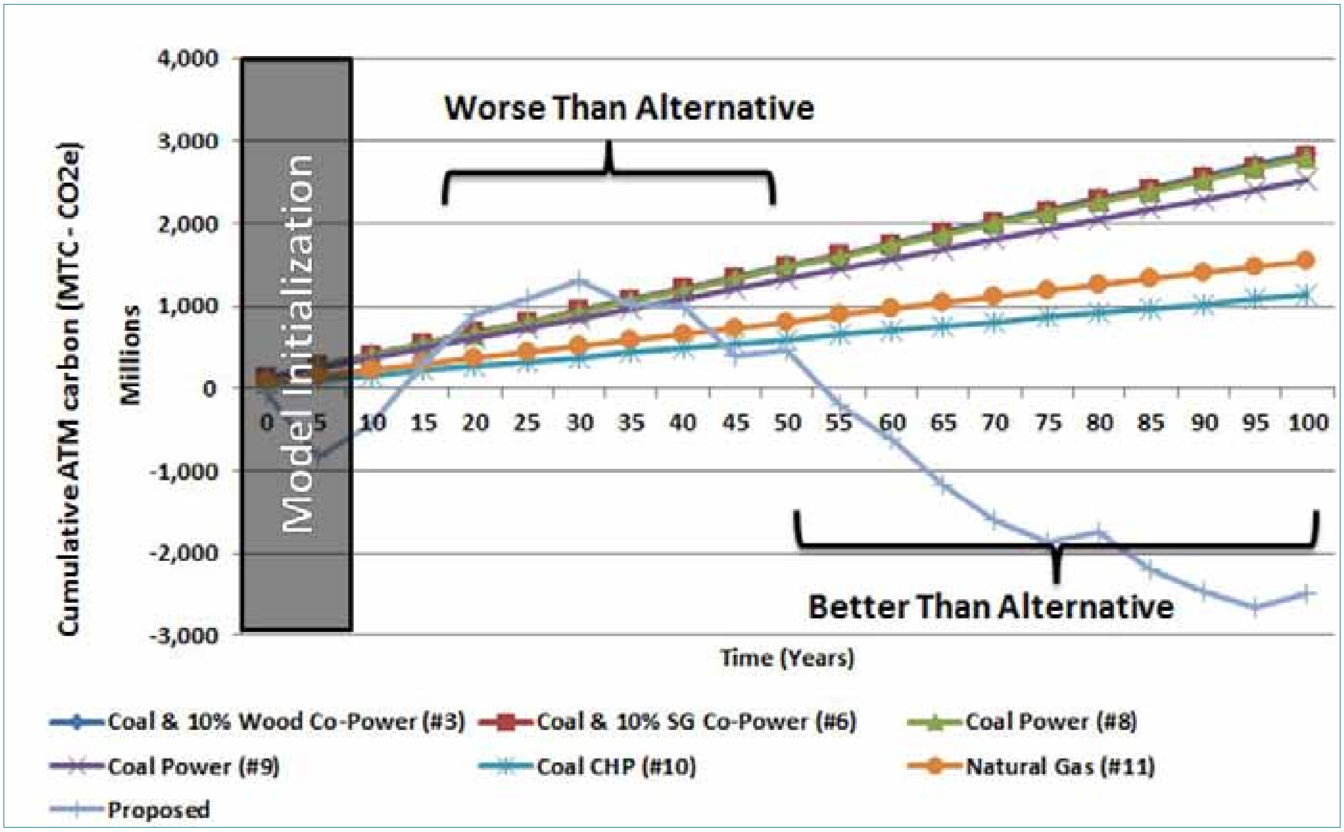


Figure 22.

Cumulative atmospheric carbon balance over 100 years using coal, and natural gas technologies to meet energy demand of proposed biomass facilities.

Biomass baseline for proposed facilities is shown for comparison. Coal #3 and #6 are hidden under coal #8. These results were based on the following assumptions: Forest Supply 50%, Pulp Supply 50%, Non-Merchantable Supply 60%, and Pellet Export 90%.

Assuming full build-out of the currently proposed facilities using biomass energy, we examined the atmospheric carbon balance effects of varying assumptions regarding pulpwood utilization, residual extraction from the forest, amount of woods-supplied versus residue-supplied raw material, pellet mill exports, and biomass efficiency.

Biomass Facility Build-out

A full build-out of the currently proposed biomass facilities requires biomass harvesting to occur in the woodsheds of those facilities. Relative to the existing facility situation this causes a reduction in stored carbon, which varies over time. Figure 21 shows the stored carbon for the existing biomass facility and full build-out facility scenarios, along with the difference between the two scenarios. The difference characterizes the stored carbon impacts of the 22 proposed facilities. The curve generally shows an increase in atmospheric carbon between the two scenarios for about 40 years before leveling off.

The actual shapes of the cumulative carbon balance lines (red and green lines) in Figure 21 will vary depending on many policy and market factors. We are not attempting to make a prediction of the actual future condition, but are interested in a realistic depiction of the difference between the two scenarios. The initial apparent sequestration in the graph is a modeling artifact. It is a function of the simulation resolution and is due to the 5-year simulation cycle with harvests simulated mid-decade. This creates a 5-year growth period before harvest simulation.

3. ATMOSPHERIC CARBON ANALYSIS *(cont'd)*

Comparison of Biomass to Other Technologies for Build-out

The use of the proposed biomass facilities for full build-out was used as a reference to compare against other technology options for meeting the same energy demand. Figure 22 on the previous page shows the cumulative atmospheric carbon balance for various fuels and technologies relative to producing the same amount of energy using biomass for the proposed facilities. These scenarios include the carbon storage that would have occurred without the proposed biomass facilities being utilized.

In all cases the alternatives appear to have fewer net atmospheric carbon emissions than biomass for 35-50 years with biomass having fewer emissions after that time.

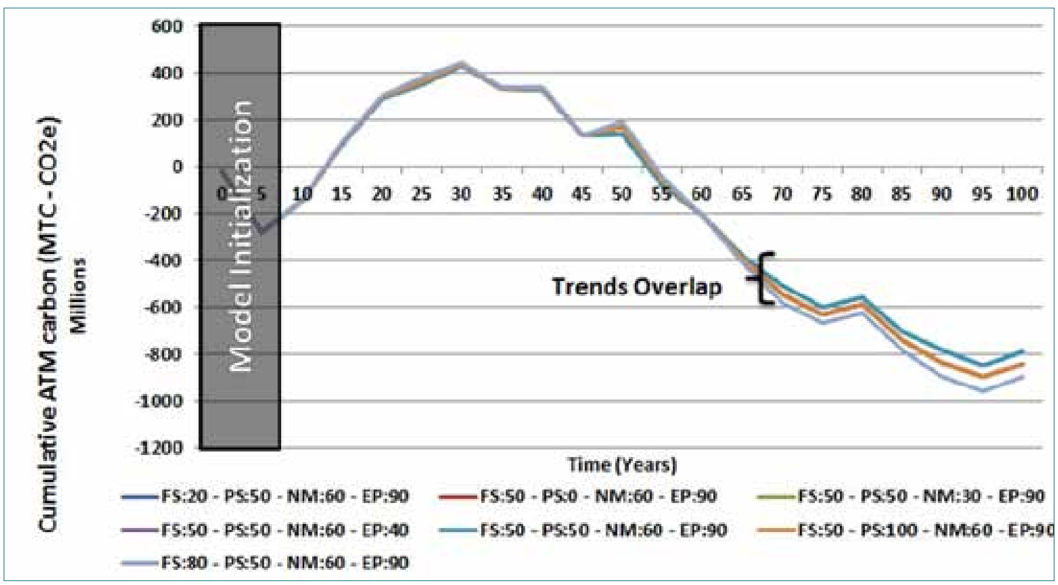


Figure 23. Sensitivity Analyses Conducted for New Biomass Facilities.

Results are presented in the following order: Wood Supply Directly from the Forest (FS: Forest Supply) at 20, 50 and 80 percent, Wood Supply from Pulpwood (PS: Pulp Supply) at 0, 50, and 100 percent, Wood Supply from Residuals (NM: Non-Merchantable Supply) at 30 and 60 percent, and Export of Wood Pellets (EP:Pellet Exports) at 40 and 90 percent. The table is keyed in the following format: Forest-Pulp-NonMerch-Pellet. None of these changes caused a substantial shift in atmospheric carbon.

The CHP scenarios for coal was the best due to the efficiency improvements with CHP. In general, natural gas performed the best of the nonrenewable fuel/technology scenarios without CHP technology (Figure 22, #11 line). Coal power showed a range of responses that depended on the technology pathway. Soil sequestration and land-use change were not considered with any scenarios.

The performance of the proposed biomass facilities relative to the other fuels/pathways was primarily due to the change in forest and long-term carbon storage that was modeled to occur with the increased biomass demand. These results were examined when the input parameters were varied.

Sensitivity Analysis of Full Build-out Using Biomass

A number of input assumptions were varied to observe the response in atmospheric carbon for the 22 proposed biomass facilities. Four primary sensitivity parameters were analyzed: wood supply directly from the forest, wood supply from pulpwood, wood supply from residuals and the amount of export of wood pellets to Northern Europe. In addition, the assumptions regarding the efficiency of the biomass facilities were varied for an additional analysis. None of the four primary input assumptions showed a substantial shift in atmospheric carbon (see Figure 23 on the previous page). The biomass efficiency assumption was analyzed separately for the full build-out scenario and is illustrated in Figure 24 on page 98.

IMAGE COURTESY ZANDER EVANS

3. ATMOSPHERIC CARBON ANALYSIS *(cont'd)*

Figure 24.

Facility Efficiency.

Both systems have short- term cost and a long-term benefit. When the biomass line is above the fossil fuel line, then it is emitting more carbon into the atmosphere compared to the fossil fuels. The atmospheric carbon impact is the same where the lines intersect. Carbon neutrality is achieved when the biomass line intersects the origin. This simulation was run using the following assumptions: (Forest Supply) 50%, (Pulp Supply) 50%, (Non-Merchantable Supply) 60 %, and (Pellet Exports) 90%.

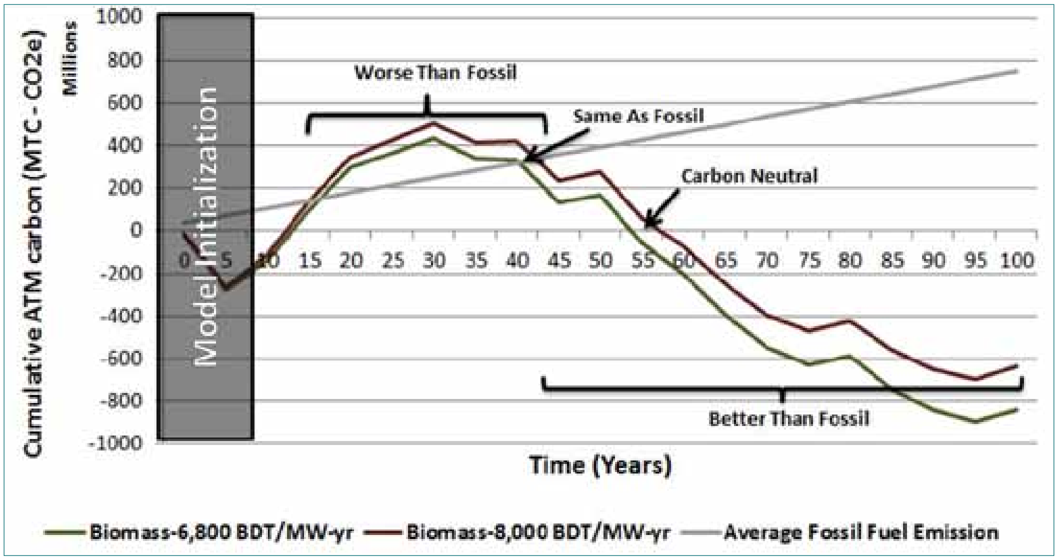
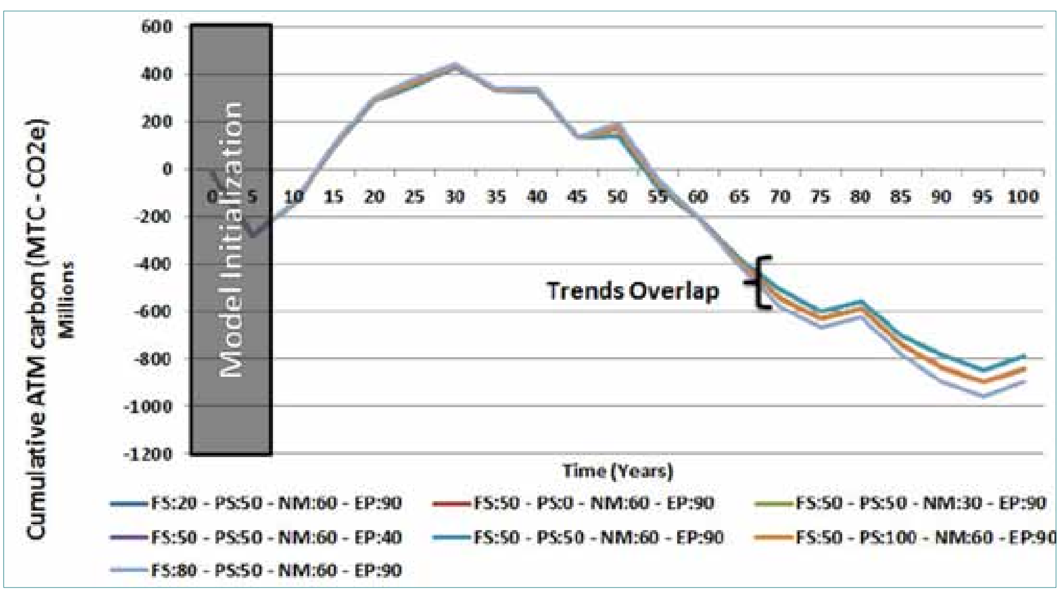


Figure 25.

Sensitivity Analyses Conducted for Wood Supply Directly from the Forest (Forest Supply) at 20, 50, and 80%, Wood Supply from Pulpwood (Pulp Supply) at 50%, Wood Supply from Residuals (Non-Merchantable Supply) at 60%, and Export of Wood Pellets (Pellet Exports) at 90%. The table is keyed in the following format: Forest. FS:20 and FS:50 overlap.



3. What are the GHG consequences of varying the amounts of biomass required to make a specific amount of electricity?

Results. Biomass utilization per unit of power produced was a critical factor and can alter the outcome of the atmospheric carbon balance over time. We showed that a more conservative (higher) assumption of biomass demand per unit of power produced altered the eventual outcome and delayed the breakeven point relative to the other fuels and pathways. There are a range of values associated with how much biomass is required to produce a given amount of electricity. Using a mid-range target of 6,868 BDT per MW per hour per year provided the payback period of 35-50 years. The model was sensitive to this parameter and payback periods were extended when the high range of about 8,000 BDT was used.

Explanation. The model was sensitive to the biomass facility efficiency assumptions. The proposed facilities are compared to the other fuel and technology pathways assuming the high end of a range of possible biomass requirements for power production (see Figure 24 on the previous page). In this figure, the other technology pathways were averaged to achieve a single carbon accumulation line. The less-efficient assumption yielded higher cumulative atmospheric carbon due to the fact that the facilities consumed a larger amount of biomass. Specific details behind this value can be found in the technology pathways section of the report.

4. What are the GHG consequences of using forest-derived biomass versus non forest-derived biomass?

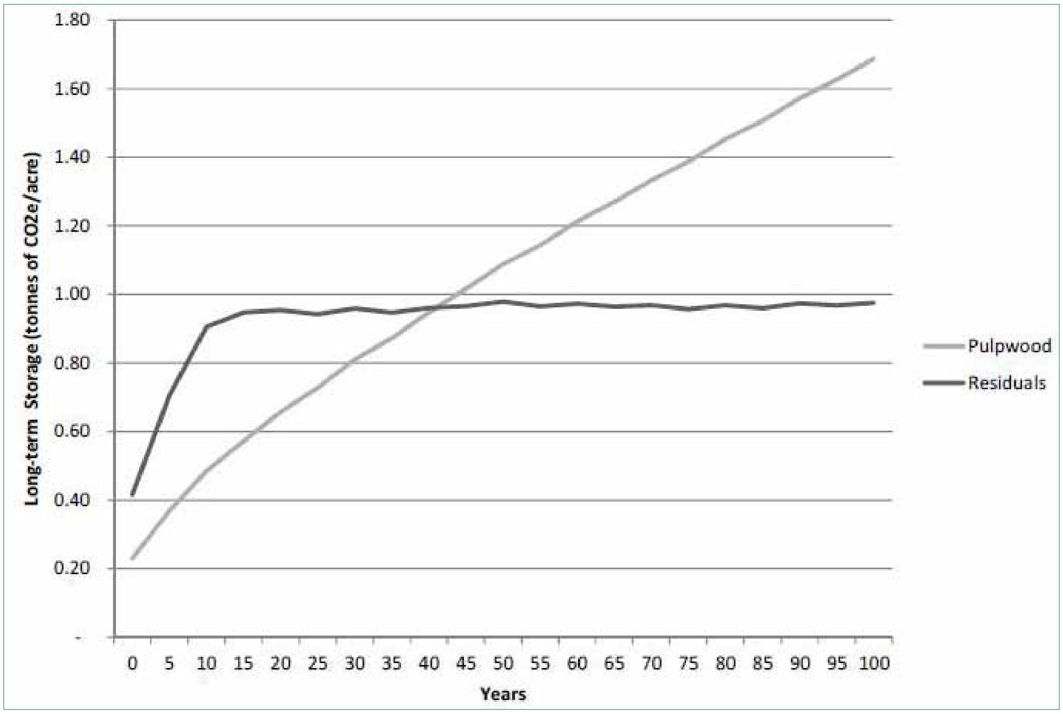
Results. The forest supply sensitivity analysis did not cause a substantial difference for the scenarios modeled at the landscape scale.

Explanation. There was sufficient biomass supply from the forest for the existing and proposed facilities within the landscape of interest using the defined assumptions. The model used the best available information on specific facility use of forest versus non forest-derived biomass. Local supply issues could occur where facility woodsheds overlap, which could have ecological impacts if best management practices for wood retention are not in place. Some biomass facilities receive 100 percent of their biomass supply from the forest or from non-forest sources such as mill residues or urban tree trimmings. Some facilities, however, claim a variable amount of their supply directly from the forest; for those facilities we varied the forest supply by setting it at 20 percent, 50 percent, and 80 percent. The sensitivity analysis does not show a substantial difference between these scenarios over the short term (see Figure 25 on the previous page). Over the long term, the results indicate a slightly lower atmospheric carbon profile for supply coming directly from the forest. Our results were surprising. We expected a benefit from using non-forest biomass feedstocks considering that this biomass has lower processing and transportation emissions as well as avoided decomposition emissions benefits. We found that at the regional scale there were no significant differences in landscape level GHG accumulation because the integrated carbon profiles of the different feedstocks were similar to one another (the net magnitude of emissions between the processing, transportation, and avoided decomposition) and the forest was responding with increased growth and storage of wood products when forest material was harvested for biomass.

3. ATMOSPHERIC CARBON ANALYSIS *(cont'd)*

Figure 26.

Example of the relative carbon storage over time of pulpwood utilized for pulp and paper products versus residuals retained in the forest.



5. What are the GHG consequences of using tops and limbs (residuals) for biomass supply versus pulpwood (main stems)?

Results. The residual versus pulpwood supply sensitivity analysis did not cause a substantial difference for most of the scenarios modeled at the landscape scale, however, this result needs to be considered in the context of the model. The use of residuals versus main stems would reduce atmospheric carbon accumulation in those situations where there are adequate amounts of residuals available from current harvests. This conclusion is based on the higher relative carbon storage of pulpwood versus residuals (see Figure 26 above). This general rule also holds true for situations where no pulp market exists and standing trees might be left to grow and sequester carbon.

Since residuals are not the driver of timber harvests, when a landscape model is asked to service biomass facilities only from residuals and the required amount of residuals is not readily available from timber harvests, it causes more acres to be harvested. Thus, when this model was instructed to supply the 22 new facilities with only residuals, it did not cause a substantial difference in the GHG consequences versus pulpwood.

An accurate depiction of the pulpwood versus residual utilization comparison requires a spatially specific and market dependent analysis beyond the scope of this study. Such a study would incorporate different market scenarios that would influence the carbon emissions such as: active sawtimber market, active sawtimber and pulp market, no markets, and active pulp market.

Explanation. An analysis of pulpwood utilization relative to residuals is complicated by the fact that more acres are generally required using residuals to supply the same quantities of biomass. Since harvests are integrated for sawtimber, pulp, and residuals, the emissions increase to obtain residual biomass supply because more carbon is removed from the forest through more harvesting. These results at the model scale should not lead to erroneous conclusions regarding the GHG differences of standing trees versus residuals because residuals are not drivers of timber harvest, but rather by-products. This comparison does not include leakage effects that might occur if biomass demand were to cause pulpwood supply to shift to other areas.

Pulpwood

The percentage of pulpwood utilized relative to harvest residuals was varied at 0, 50, and 100 percent of pulpwood utilization. In the context of the entire study area, there was not a substantial tradeoff identified between utilizing pulpwood that was destined to be made into pulp and paper products and using the same material for biomass energy (see Figure 27 below). This was not a complete life-cycle analysis in that the pulp and timber markets were not analyzed, including potential leakage effects of displaced pulp supply.

Designing a More Accurate Model for the Residuals versus Main-Stems Question

A complete depiction of the pulpwood versus residual utilization comparison requires a spatially specific and market-dependent analysis beyond the scope of this study. For simplicity in framing the conceptual model, we are assuming that no competition from other biomass facilities exists, however, the map of existing and proposed facilities (see Figure 11 on page 72) shows that a number of facilities have overlapping sourcing areas. This could cause a situation where biomass is being moved farther distances for use in facilities designed with different efficiencies driven by specific market demands.

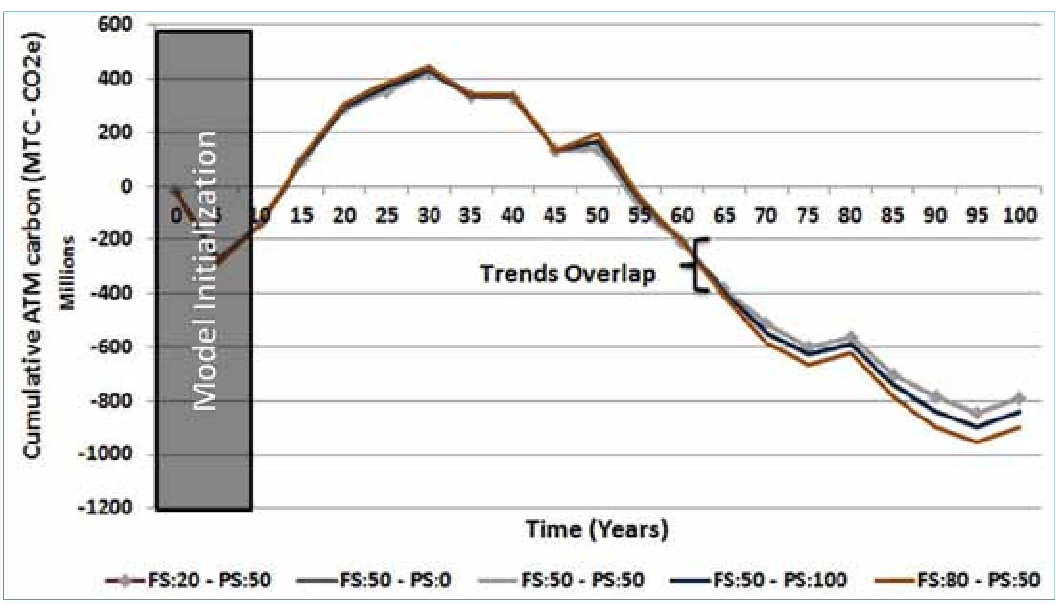


Figure 27.

Sensitivity Analyses Conducted for Wood Supply Directly from the Forest (Forest Supply) at 20, 50, and 80% and Wood Supply from Pulpwood (Pulp Supply) at 0, 50, and 100%, Wood Supply from Residuals (Non-Merchantable Supply) recovered at 60%, and Export of Wood Pellets (Pellet Exports) at 90%. The table is keyed in the following format: Forest-Pulp. FS-PS, 20-50, 50-50, and 50-0 all overlap.

3. ATMOSPHERIC CARBON ANALYSIS *(cont'd)*

Market demands could be incorporated into a future study by defining different market scenarios that would influence the carbon emissions such as: active sawtimber market, active sawtimber and pulp market, no markets, and active pulp market.

Scenario 1-Active Sawtimber Market. This setting includes intensive sawtimber activity in the proposed facility woodshed and no existing pulp demand. In this case, we assume that an ample supply of both residuals and pulpwood is available. Since there is no existing residual or pulpwood demand, we can assume that when a sawtimber harvest occurs, this wood is either left to become emissions over time from decay if part of a sawtimber tree, or if a partial harvest, left on the stump. The larger harvested pulpwood pieces will take longer to decay so there is a timing element, but in general either of these sources for biomass would have the same atmospheric carbon effects when derived from sawtimber trees. This is because neither source was being utilized a priori. Leaving the pulpwood-size pieces on the stump and utilizing the residuals from the harvested sawtimber, however, will clearly be beneficial from an atmospheric carbon perspective.

Scenario 2-Active Sawtimber and Pulp Market. This setting includes intensive sawtimber activity in the proposed facility woodshed and existing pulp demand. In this case, we assume that an ample supply of residuals exists, but pulpwood is already being utilized for paper products with the associated long-term storage in in-use and landfill pools. Since there is no existing residual demand, we can assume that when an integrated sawtimber and pulpwood harvest occurs that the residual wood is left to become emissions over time from decay. In general, using residuals will have improved atmospheric carbon effects relative to pulpwood. This is because the residuals were not being utilized a priori while a portion of the pulpwood was placed into long-term (100-year) storage. Taking the pulpwood instead of the residuals would cause the long-term storage to be negated; this would be offset in the shorter term by more residuals in the woods but that would reach a steady state. Also, if this meant a displacement of pulp supply, then the carbon analysis would depend on the leakage effects. This scenario fits with much of the "existing" landscape condition in the Southeast; except of course for the recent drop-off in timber production. For example, sawmills in Alabama are currently running at about 50 percent capacity.

Scenario 3-No Markets. This setting includes a low level of sawtimber activity in the proposed facility woodshed and no existing pulp demand. In this case we assume that a low level of supply of both residuals and pulpwood is available. In order to provide biomass supply, harvests would have to be initiated based on biomass demand, not as a side consequence of other harvests. In this case it might seem logical to utilize both pulpwood and residuals from harvests. This might minimize the reduction of stored carbon in the forest, not considering land conversion issues, by minimizing the acres harvested. Relative to a baseline of no harvest, however, this would not be beneficial to the atmospheric carbon balance. There would likely be some acreage in this category where a biomass market may make marginal harvest scenarios profitable. We did not attempt to quantify this effect for the study area.

Scenario 4-Active Pulp Market. This setting includes a low level of sawtimber activity in the proposed facility woodshed and an existing pulp demand. In this case, we assume that a supply of both residuals and pulpwood is available, but pulpwood is already being utilized for paper products with the associated long-term storage in in-use and landfill pools. Utilizing the residuals associated with pulpwood harvests would have the most beneficial carbon effect. This illustrates that a pulpwood- versus residual-utilization question is really a site specific one, which has policy implications regarding GHG accounting for a proposed facility. Our modeling did not account for this level of sophistication, which would require a spatially explicit timber/pulp supply model.

Professional forestry and forest management have long been involved with the sustainable production of wood fiber for use by society. The production of wood fiber for biomass energy affects the amount of carbon exchange between the biosphere and atmosphere through both the production of energy and carbon stored on the landscape and in other pools. By accounting for these flows, we can identify when landscapes may become limiting to sustainable and environmentally favorable outcomes. We have assumed in our modeling here that any harvesting will be followed by replanting or natural regeneration so that all stands are fully restocked in a reasonable and relatively short time frame.

This analysis can inform policy and management decisions. We can also use our existing tools of silviculture and planning to assist with mitigating effects where feasible for the best environmental and economic outcomes. The accounting for the consequences of atmospheric carbon balance relative to a baseline that is geographically constrained to the affected area is consistent with project carbon accounting as found in forest protocols for carbon projects.

6. What are the GHG consequences of using natural stands versus plantations to fuel an expansion of biomass electric power in the Southeast?

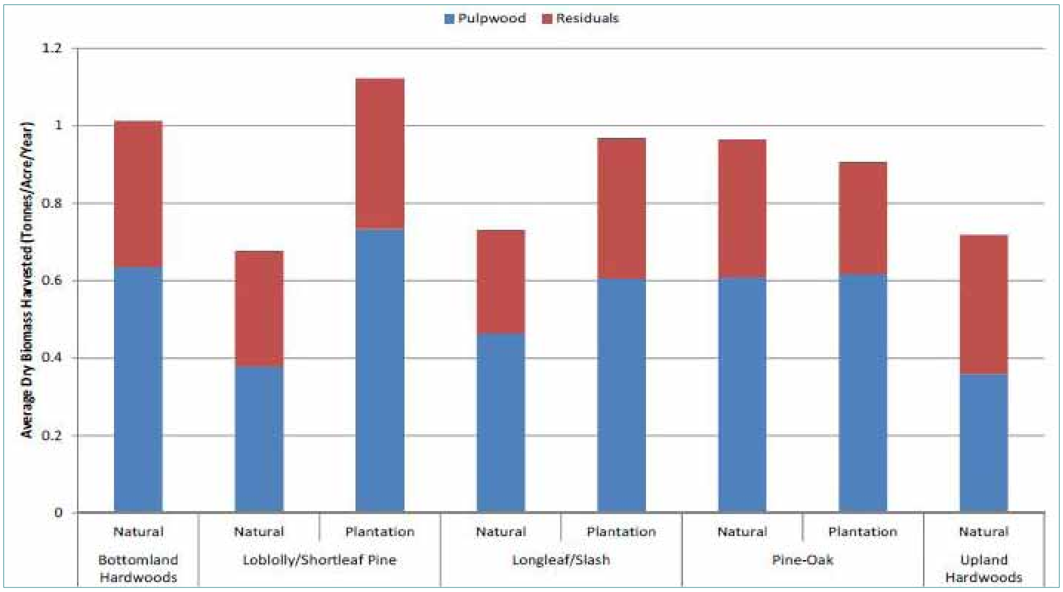
Results. The model design did not allow a direct comparison of natural stands versus plantations at the stand level, however, additional research indicated that converting from natural bottomland hardwoods to a loblolly pine plantation would have substantial negative carbon storage effects, and should probably be avoided. This could also be true for converting upland hardwoods. We also found that for a given acre, plantations can produce more biomass than natural stands over time. This may be a function of site productivity, improved genetic stock from planting, and silvicultural methods. For example, loblolly plantations produced considerably more biomass than natural upland hardwoods, but stored less carbon than upland hardwoods. This did not hold for the pine-oak forest types. The bottomland hardwoods, which are regenerated naturally, were highly productive second only to loblolly/shortleaf pine plantations. We did not find substantial GHG effects, however, at a regional scale.

Explanation. The model considers existing plantations at the study scale and was not designed to alter the amount of plantations nor the effects of converting natural stands to plantations, however, additional research was useful in providing information about the difference between natural stands and plantations. The average carbon stored over 100 years by forest type and stand origin is shown in Figure 29 on page 105. In general, the naturally regenerated hardwood types stored more carbon than softwood types. The baseline management, which assumes sawtimber and pulp production but not biomass, generally stored more carbon than when biomass management is added. There was not a clear pattern of carbon storage for the forest types that had both plantation and natural stand regeneration.

3. ATMOSPHERIC CARBON ANALYSIS *(cont'd)*

Figure 28.

Average biomass produced (harvested) over 100 years for the study area, by forest type, and stand origin.



In some forest types, plantations can grow more biomass than natural stands. This does not imply, however, that conversion of natural stands to plantations should occur to meet demand. The current placements of plantations were in response to economic and social choices in the past, which may not apply to existing natural stands since they represent different productive, ecological, and economic conditions. Naturally regenerated stands may also store more carbon while also producing substantial biomass feedstock as the bottomland hardwoods clearly show. Figure 29 on page 105 shows that in the forest types where plantations occurred, more than 50 percent of the area is already in plantations.

In areas where the pulp market has declined, biomass demand may provide a market for existing plantations. This would be beneficial to the atmosphere if the market prevented conversion from forest to other uses. Degraded natural stands could also benefit from a biomass market where improvement treatment costs could be offset by selling biomass.

Several additional elements would need to be added to this comparison to achieve accurate predictions of impacts to atmospheric carbon. These would include: harvest recovery technology, transportation distances and efficiencies, and biomass utilization efficiencies.

There is a general atmospheric carbon benefit associated with dense biomass recovery locations that are found in close proximity to efficient biomass facilities. In addition, sustainable forest management practices are a necessity to avoid a release in stored forest carbon. There are also examples where biomass utilization has made restoration efforts economically feasible. These elements should all be taken into consideration when prioritizing between natural stands and plantations.

It should also be noted that we are assuming all plantations harvested will be replanted. There may be instances when the landowner sells his plantation stands for biomass and then converts the land to development. Since we did not take into consideration land-use/ land-cover changes within the model, this carbon would not be recaptured and should be considered as an emission. Since forest carbon regeneration is a key component to landscape level GHG emissions; credit should be given only to areas where regeneration is an explicit part of the long-term management plan. Landholdings that are currently forested, and then are type converted into another non-forest land use (such as a development) should be explicitly excluded from regional GHG benefits assessments or quantified as a long-term emission.

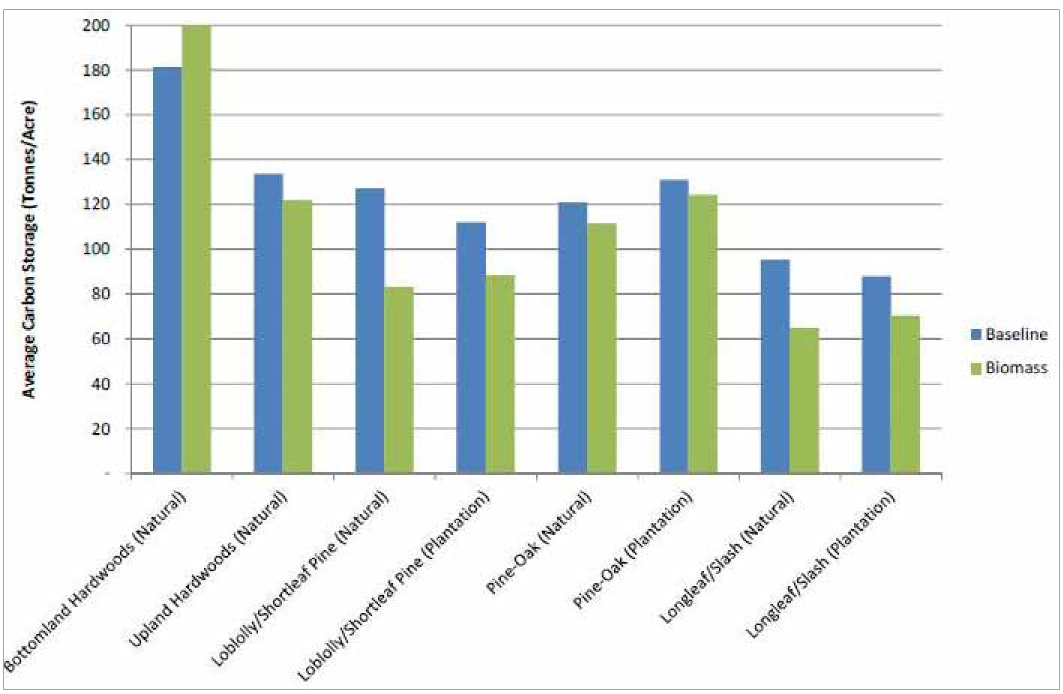


Figure 29.

Average carbon (CO_2) stored over 100 years for the study area, by forest type, stand origin, and management regime.

3. ATMOSPHERIC CARBON ANALYSIS *(cont'd)*

7. What are the GHG consequences of varying levels of pellet export from the Southeast to Europe for electric power generation?

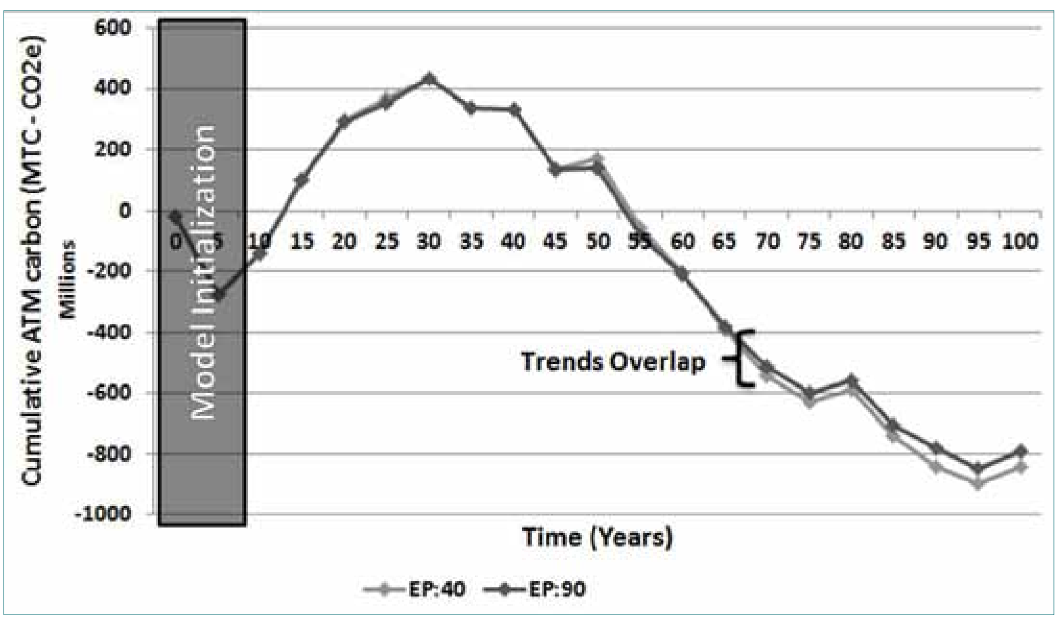
Results. The current biomass facilities and full build-out of currently proposed facilities scenario were not highly sensitive to the amount of wood pellets that were exported.

Explanation. A factor analyzed in our sensitivity analysis was the exporting of pellets. Our default setting was an assumption of 90 percent exports to Northern Europe. We also examined the effects of reducing the export of pellets to 40 percent.

Figure 30 below shows that reducing the export of pellets does not substantially improve the atmospheric carbon balance of using biomass for the proposed facilities. This is a factor of the relatively small atmospheric carbon cost of shipping pellets as ocean freight. It is important to note that the European Union (EU) is not accounting for the carbon emissions from burning wood pellets. Rather, the EU Emissions Trading System considers biomass resources to be carbon neutral and European industries are essentially getting a free pass on biomass carbon accounting. The wood pellet manufacturing, shipping, and combustion costs as well as the sequestration effects of wood products and in-forest carbon are all factors in a comprehensive carbon accounting.

Figure 30.

Cumulative atmospheric carbon balance over 100 years using the 40% and 90% export options. Wood Supply Directly from the Forest (Forest Supply) at 50 percent and Wood Supply from Pulpwood (Pulp Supply) at 50 percent, and Wood Supply from Residuals (Non-Merchantable Supply) at 60 percent. The table is keyed in the following format: Export %.



8. Is there enough biomass available to supply 22 new biomass facilities while limiting the amount of residuals that can be removed to protect forest health?

Results. Although the sensitivity analysis did not indicate a significant change in carbon balance related to the amount of residuals allowed for removal, the analysis did indicate that limiting the amount of removal of residuals to either 30 or 60 percent of what is available after harvests did not present a limiting factor to supply at the scale and using the current model construct (see Figure 23 on page 96). This indicates that at least for the proposed additional capacity modeled, retaining sufficient residual biomass to maintain ecological health should not be limiting to biomass supply.

Explanation. There are physical, economic, and Best Management Practice limits to how much of the residuals (non-merchantable wood, bark, and foliage) can be removed from the forest. The results indicate that there is enough available material in other categories to fill a limitation on residual removal. The existing landscape, its current land use, existing markets, and energy demands provide a matrix where there is sufficient feedstock availability given the assumptions used in the analysis. Forest management practices that were used in this study reflect current methods. These methods could be improved upon to yield healthier forests and a more stable future feedstock for facilities that are scaled appropriately to the landscape that they serve. In short, there has to be sufficient activity on the landscape to produce the residuals or a difference will become apparent.

3.5.0 POLICY CHALLENGES: INCORPORATING FOREST BIOMASS AND CARBON MODELING INTO SOUND CLIMATE CHANGE POLICY

The Challenge of Evaluating Forest Carbon Flux

Recent studies at the Massachusetts Institute of Technology (MIT) reveal that participants from highly educated study groups repeatedly used flawed conceptual reasoning and violated fundamental physical principles when asked to anticipate the atmospheric effects of basic approaches to controlling carbon emissions (Sterman, 2008; Sterman 2007). People have difficulty conceptualizing flows of carbon stocks between different carbon pools such as forests and the atmosphere. Researchers confirm that the survey participants produce the wrong answer when they use a problem-solving approach called pattern matching to assume that an output of a system should look like its inputs. Researchers call this "stock-flow failure" (Cronin, 2009).

In the MIT studies, this stock-flow failure led people to believe that GHG accumulation in the atmosphere could be lowered merely by lowering the yearly emissions (Sterman, 2007). In other words, they believe that simply lowering the rate of emissions would lower the total stock of carbon in the atmosphere. In reality, however, GHG concentrations in the atmosphere can fall only when emissions drop below sequestration rates.

3. ATMOSPHERIC CARBON ANALYSIS *(cont'd)*

Furthermore, in the real world, time lags and movement between different types of carbon pools create complexities that create even greater challenges for those crafting climate change policy (Sterman, 2006). To assist readers in applying the results of this report and to assist the policy discussion, the following guideposts may be useful.

The Fundamental Cause of Long-Term Atmospheric Carbon Accumulation

Climate is changing due to increased levels of carbon in the atmosphere. Atmospheric carbon is increasing primarily because we burn fossil fuels and release carbon that was sequestered in geologic formations millions of years ago. Forest destruction and large-scale land-use change also increase atmospheric carbon. Forests and other carbon pools such as oceans, rocks and sediments, grasslands, or peatlands can sequester carbon but cannot absorb net increases in atmospheric carbon from combustion of fossil fuels or large-scale deforestation fast enough to be meaningful for environmental policy over the next few centuries. Forests re-sequester carbon relatively quickly but the worldwide forest pools cannot deal with the tremendous amount of carbon already released from both the fossil carbon pool and the forest carbon pool (31 gigatons in 2009) nor future releases from these pools (Henson, 2011). The full level of atmospheric carbon loading will eventually be determined by the total amount of carbon released from combustion of fossil fuels and conversion of forests to non-forest uses.

We have already added 300 gigatons of carbon pollution to the atmosphere over the last 150 years. The IPCC low-growth emissions scenario B1 anticipates the addition of another 700 gigatons. Regardless of final carbon levels, it is clear that it will take thousands of years for oceans, rocks and sediments, and terrestrial systems to reabsorb this carbon (Stager, 2011). This means that the effects of our current fossil fuel use will be felt by human beings and the earth's ecosystems for a long time. The management, harvest, destruction, and creation of forests will play a role in this situation, particularly in the short term, but over the long run, the story will be largely dictated by the total amount of fossil fuel carbon we release.

Acknowledging Long- and Short-Term Perspectives

The results of atmospheric life-cycle carbon assessments will prompt analysis from two different perspectives, both of which are necessary for development of effective climate policy. Those holding a long-term perspective will pay attention to the levels of atmospheric carbon that will be realized over centuries and millennia. The operative question for these long-term thinkers trying to determine the effects of atmospheric carbon on global climate is not how much we are emitting on a yearly basis (the flow) but what will be our total fossil fuel emissions (the stock) over time. Individuals with a long-term perspective will note that forest biomass is a biogenic source of energy and see the decades-long forest carbon debt and payback flux as relatively inconsequential in the long run—a mere short-term biogenic carbon flux in the context of the larger relatively permanent global geologic carbon flux.

Individuals with shorter-term perspectives will likely interpret the results of the current study differently and ask different questions. If there is a carbon emissions level policy target that is only decades away, then the use of more forest biomass may not help meet that specific short-term goal. A series of other questions will arise from the short-term perspective. What damaging climate events might be triggered through additional short-term carbon loading of the atmosphere? How do we weigh the short-term increase in carbon emissions from biomass against the larger longer-term benefits of substituting biomass for fossil fuels? How long will we utilize fossil fuels, when do we anticipate a total global switch to non-fossil alternatives, and how will the debt cycle of forest biomass overlap with that transition? Will an early emphasis on forest biomass help us transition to carbon-free alternatives like solar or wind or will it delay their implementation? Are there hidden ecological or carbon costs in the use of forest biomass of which we are not now aware?

Balancing Long- and Short-Term Perspectives

Two factors are critical to setting policy that balances the complicated short- and long-term flux dynamics of forest biomass. The first one is an estimate of when we can expect to transition fully away from fossil fuels. If this transition lies within the debt cycle of biomass systems, the policy response will be different than if the transition lies outside the debt cycle of biomass. In either case it should be realized that when full transition occurs that is also the point in time when biomass plants could theoretically be shut down and the forest allowed to recover and re-sequester the carbon that the biomass energy system has moved to the atmosphere while it was operating. (Of course this assumes that biomass harvesting is followed by forest regeneration and not the conversion of forest land to other uses.) An accounting and comparison to other alternatives could include this re-sequestration that would begin at this time.

The second factor pertains to the goals of climate policy—what policies are adopted to mitigate the effects of climate change to society and ecosystems. At some point in the future there will be an atmospheric carbon peak followed by a variety of physical global warming responses related to that peak. The warming will lead to climate events that will have repercussions on human society and natural ecosystems. Recognizing the linkages and timing of these events and matching them to the stocks and flows of forest carbon will be critical in setting the most effective policies.

The combustion of biomass for energy and subsequent release of carbon into the atmosphere is linked to a sequestration component when the material is produced from sustainably managed forests. Carbon is initially released as forests are harvested for biomass, and then re-sequestered over time as the forest recovers. This is unlike fossil fuels, which have no sequestration component. Biomass also has a longer payback period than other renewables such as wind and solar. Consequently, the carbon implications of biomass are much more difficult to decipher and prone to an endemic confusion over stocks and flows. It is neither immediately carbon neutral, nor can the payback periods be summarily dismissed as unhelpful to climate goals. Therefore, biomass deserves a full and comprehensive discussion of its potential to help meet climate change goals through close attention to proper GHG accounting methodologies.

CONCLUSIONS

OVERALL

This study confirms that the life-cycle carbon implications of biomass when used for energy production are complex and do not lend themselves to simple or blanket public policy options. It is important to remember that the results in this study apply only to an analysis of biomass electric power and electric-led CHP in a specific region of the southeastern United States. It does not apply to thermal-energy pathways as these have significantly higher efficiencies and consequently different carbon life-cycle analyses. Nor does it directly apply to other regions with different forest types, utilization trends, or market conditions.

Forestry and forest management have long been involved with the sustainable production of wood fiber for use by society. The production of wood fiber for biomass energy affects the carbon exchange between the biosphere and atmosphere. By accurately accounting for this exchange through a full life cycle carbon analysis, this study illustrates how utilizing our forests for biomass energy can affect yearly emissions and the eventual accumulation of green house gases in the atmosphere when compared to using fossil fuels. The manipulation of important parameters in the model also allow us to test which policy and forest management decisions may create a more or less positive outcome for the use of biomass. These results can be combined with other factors, such as a weighing of short and long term carbon accumulation in regard to damaging climate events or the ecological effects of harvesting more biomass to inform policy and management decisions.

WOOD SUPPLY

- Most studies conducted in the past six years quantify the gross or total amount of woody biomass material generated on an annual basis and do not quantify how much is already being used. Most of these studies focus on residues produced from other primary activities while evidence suggests nearly all the mill and urban wood residues are already used by existing markets.
- The evidence clearly suggests that any expanded biomass energy in the Southeast will come from harvested wood (either tops and limbs left behind from timber harvesting, whole trees, or pulpwood sourced from the main stem of a harvested tree).
- Whether logging slash, whole trees, or pulpwood will be used in the expansion of biomass energy in the Southeast will depend on:
  1. Which market the wood is going to (pellet mills need high-quality fiber from pulpwood while biomass plants are less particular about quality)
  2. How much demand increases within the pellet and power market sectors over time
  3. What happens with the pulp and paper industry in the southeast region in the future
- Prior to 2009, most fuel availability studies presented estimates of supply without any acknowledgment of the influence price has on the availability of these woody biomass resources. Since then, different studies have examined the economics using different indicators, making it

difficult to compare results between the studies. For a clear assessment of the economics of woody biomass resources, the total delivered price paid by the receiving facilities is the best indicator to use.

- Various studies reviewed in this chapter used widely divergent assumptions regarding what percentage of the total amount of logging residue can be recovered from a harvested area. While the range observed in the literature was from roughly 50-100 percent, it should be noted that there is a difference between how much residue *can* be recovered and how much *should* be recovered when ecological factors are taken into account. While examining how much wood fuel could be generated if 100 percent of this material was recovered is useful for academic purposes, it is unrealistic to assume that such a high level can and should be realized. Ideally, studies would look at two critical issues when factoring the overall recovery rate—percentage of recovered residues on individual harvest operations and percentage of harvest operations where residues can be recovered.
- The availability of logging residues will largely depend on extraction methods. Where whole-tree harvesting systems can be used, these residues can be cost-effectively accessed, however, the ecological effects of whole-tree logging need to be considered. Where mechanized cut-to-length and manual stem-only harvesting are used, these residues will not be easily accessible. Further analysis that determines how much whole-tree harvesting systems versus stem-only harvesting systems are used across this region would be very useful.
- Of all the states in the seven-state study region, North Carolina has had the most in-depth and sophisticated level of study of its biomass energy potential. In contrast, Alabama and Tennessee both had very little publicly available reports estimating biomass resources.
- Evidence suggests that there is likely enough wood to meet a 15 percent federal RES standard applied to each of the seven states (with the exception of Florida) when woody biomass sourced from local forests accounts for no more than 20 percent of the overall renewable electric generation target. It also appears, however, that adequate wood fuel resources are quite sensitive to the RES allocation. For example, if 30 percent of a 15 percent RES was allocated to forest biomass, it is likely there would not be enough wood fuel available within the region. A more aggressive RES standard for biomass leads to a higher likelihood of shortages and a greater probability of pulpwood displacement.
- Capacity to access and utilize residues is also a function of how much roundwood harvest occurs. More demand for roundwood generates more residues. The extent to which biomass power plants transition their wood procurement away from residues and toward roundwood is governed by the strength of the rest of the forest products industry. If the forest products industry strengthens as a result of greater lumber demand, it will increase its wood fiber consumption and, as a result, biomass power plants would procure more residues at a lower cost and less pulpwood at a higher cost. If the forest products industry as a whole continues to contract, however, biomass power plants will likely transition toward procurement of chipped fuel from whole trees *assuming* they can absorb the higher cost associated with that transition.

While some believe that biomass power demand will likely transition to procuring roundwood and displacing wood from

CONCLUSIONS *(cont'd)*

the pulp and paper industry, it is actually more likely that growth in pellet markets—which demand higher-fiber quality found in roundwood (not slash)—will be the market that most immediately displaces pulpwood. Therefore, pellet mills and biomass power plants have somewhat complementary (almost symbiotic) procurement needs. Pellet production, especially the export market to Europe, will continue to play the wildcard role in future wood fuel markets.

- The potential recovery rate for harvest residue is a key variable in determining the quantity of available wood fuel. Further research is needed to assess both the current achievable residue recovery rates and reasonable future recovery rates. Projected recovery rates need to consider woody biomass retention rates to meet wildlife and biodiversity, water quality, and soil productivity needs.
- The supply chapter undertakes a hypothetical exercise looking at current forest growth rates versus current removals to generate some rough estimates of the state and regional potential woody biomass supply for energy. This exercise suggests that meeting 20 percent of a 15 percent renewable electricity standard with woody biomass would be possible in the Southeast region. Meeting 30 percent of a 15 percent RES would likely exceed the projected supply. This exercise points out that there are distinct limits on how far woody biomass supply in the region can go toward meeting renewable energy targets.

CARBON LIFE-CYCLE ANALYSIS

The conclusions provided here are grouped to track with the key questions the study is intended to address.

What are the atmospheric carbon implications of operating the existing 17 biomass power plants in the study region versus not running them into the future and using fossil fuel instead?

Our findings indicate that the 17 existing biomass facilities (149 MW and 1.755 million tons of pellets) now generate and would continue to generate an improved atmospheric carbon balance relative to fossil fuels to provide equivalent power. Continuing to run these existing 17 biomass power plants would result in lower atmospheric carbon in the short- and long-term than shutting them down and shifting to fossil fuels.

What are the atmospheric carbon implications of operating the existing 17 biomass power plants as compared to operating these existing plants plus 22 new proposed biomass power plants?

Answering this includes a range of sensitivity analyses, including the impacts of varying the proportions of residuals versus pulpwood and natural forests versus plantations.

Additional biomass facilities produced long-term atmospheric carbon benefits for a short-term atmospheric carbon cost. The biomass option recovered the carbon debt in 35-50 years depending on the fossil fuel scenarios being compared.

What are the GHG consequences of varying the amounts of biomass required to make a specific amount of electricity?

Biomass utilization per unit of power produced is a factor and can alter the outcome of the atmospheric carbon balance over time. We showed that a lower assumption of biomass demand per unit of power produced shortened the payback period relative to the other fuels and pathways. There are a range of values associated with how much biomass is required to produce a given amount of electricity. Using a mid-range target of 6,800 BDT per MW per hour per year provided the payback period of 35-50 years.

What are the GHG consequences of using forest derived biomass (tops, limbs, pulpwood) versus non-forest derived biomass (mill wastes and urban tree thinning)?

The forest supply sensitivity analysis did not show a substantial difference for the scenarios modeled at the landscape scale. The study does show that using non-forest biomass generally has a slightly lower atmospheric carbon profile. These results were surprising. A much larger benefit from using non-forest biomass feedstocks was expected considering that this biomass has lower processing and transportation emissions as well as avoided decomposition emissions benefits. What we found was, at the regional scale, there were no significant differences in landscape level GHG accumulation because the integrated carbon profiles of the different feedstocks were similar to one another (the net magnitude of emissions between the processing, transportation, and avoided decomposition were similar, Figure 25).

What are the GHG consequences of using tops and limbs (residuals) for biomass supply versus pulpwood (main stems)?

The forest supply sensitivity analysis did not cause a substantial difference for most of the scenarios modeled at the landscape scale. This result, however, needs to be considered in the context of the model. The use of residuals versus main stems would reduce atmospheric carbon accumulation in those situations where there are adequate amounts of residuals available from current harvests. This result is based on the higher relative future carbon storage of pulpwood versus residuals. This general rule also holds true for situations where no pulp market exists and standing trees might be left to grow and sequester carbon. Since residuals are not the driver of timber harvests, however, when a landscape model is asked to service biomass facilities only from residuals and the required amount of residuals is not readily available from existing timber harvests, it causes more acres to be harvested. Thus, when this model was instructed to supply the 22 new facilities with only residuals, it had to include more acres of overall harvest to generate these residuals and consequently did not cause a substantial difference in the GHG consequences versus pulpwood.

An accurate depiction of the pulpwood versus residual utilization comparison requires a spatially specific and market-dependent analysis beyond the scope of this study. Such a study would incorporate different market scenarios that would influence the carbon emissions such as: active sawtimber market, active sawtimber and pulp market, no markets, and active pulp market.

CONCLUSIONS *(cont'd)*

What are the GHG consequences of using natural stands versus plantations to fuel an expansion of biomass electric power in the Southeast?

The model design did not allow a direct comparison of natural stands versus plantations at the stand level. Additional research, however, indicated that converting from natural bottomland hardwoods to a loblolly pine plantation would have substantial negative carbon storage effects, and should probably be avoided. This could also potentially be true for upland hardwoods. We also found that for a given acre, plantations can produce more biomass than natural stands over time. This may be a function of site productivity, improved genetic stock from planting, and silvicultural methods. This did not hold for the pine-oak forest types. The bottomland hardwoods, which are regenerated naturally, were highly productive second only to loblolly/shortleaf pine plantations. Nevertheless, we did not find substantial GHG effects at a regional scale.

What are the GHG consequences of varying levels of pellet export to Europe for electric power generation from the Southeast?

The current biomass facilities and full build-out scenario were not highly sensitive to the amount of wood pellets that were exported and did not improve significantly as more pellets were consumed domestically.

Is there enough biomass available to supply 22 new biomass facilities while limiting the amount of residuals that can be removed to protect forest health?

Limiting residual amount removal to either 30 or 60 percent of what is available after harvests did not present a limiting factor to supply using the current model construct. This indicates that at least for the proposed additional capacity modeled, retaining sufficient residual biomass to maintain ecological health should not be limiting to biomass supply. We did not find a significant GHG affect when the amount of residuals removed was varied.

POLICY IMPLICATIONS

This analysis of using forest biomass to supply electric power generation in the Southeast replicates the multi-decade payback pattern from similar studies that integrate life-cycle carbon accounting with forest carbon accounting. This pattern remained consistent even though this study incorporated more accurate harvest regimes, operated in a region with an active pulp market, and examined specific woodsheds and facility placement as compared to other recent forest carbon modeling work. This suggests that the leading factor in the long payback periods is the low efficiency of power generation and not forest harvest or growth variables or regional forest types. Similar studies in other regions will be necessary to confirm this.

The multi-decade debt and payback periods for biomass power reinforce the benefits of using biomass for more efficient heating or cooling applications or CHP applications in regions where appropriate. It suggests a policy of prioritization for the use of forest biomass that focuses first on thermal applications where possible and appropriate and then on power applications.

Interpreting these multi-decade payback results in terms of long- and short-term climate change goals requires a deeper policy discussion than has yet occurred. Regulating atmospheric carbon for climate change goals requires sophisticated carbon stock-flow accounting—a dynamic that is not intuitively easy for the public to understand. Interjecting biomass into this accounting magnifies the challenge because the use of biomass for energy, unlike fossil fuels, comes associated with a sequestration component that must be accounted for over time. Effort should be made to more clearly represent this accounting for greater understanding and to avoid unintended faulty policy decisions.

For example, interpreting these results by relating them strictly to yearly emission targets at some specified point in time would be inaccurate as it fails to account for the eventual payback. The results of this study should prompt a closer evaluation of the short-term costs and long-term benefits and relate them to actual atmospheric carbon accumulations and climate change goals over a timeframe appropriate to the future trends of climate change.

Depending on the importance assigned to long-term benefits and short-term debt, the prospect of adding 22 new generating or pellet facilities may look favorable or unfavorable for climate goals. The carbon storage capacity of natural forests indicates it may be harmful to convert natural forest to plantations for carbon benefits even though plantations may out-produce natural stands in some situations (and this practice would have other serious ecological consequences that must be considered as well). The use of residuals, where available, would provide greater carbon benefits, however, since intensive removals of residuals could result in negative ecological impacts, the study examined the results from limiting the removals and determined there would still be adequate supply for the facilities that were modeled.

This study can be useful for policy development involving programs with incentives for biomass production and regulatory efforts. It is most readily adaptable for programs involving incentives as it allows different policy approaches to be compared and evaluated in relation to one another. The data provide a relative difference among approaches that may facilitate the ranking of different technologies for their support of climate goals and an assignment of different levels of incentives to different technologies.

CONCLUSIONS *(cont'd)*

This study may also be helpful for regulatory mechanisms. It offers EPA additional information to develop an appropriate framework for accounting for the emissions of biogenic carbon from stationary sources. In EPA's September 2011 report, it selected a "reference-point" approach for setting a baseline although it acknowledged the benefits of using the "comparative" approach used in this study. The EPA report championed the "reference-point" approach because it was "straightforward" and met a list of criteria, including ease of use, ease of understanding, and accuracy in prediction of carbon outcomes. The "reference point" predicts if the system has more or less carbon stored at the end of the assessment period than at the beginning while the "comparative" approach determines if there is more or less carbon than there would have been if the energy was created by fuel sources other than biomass. This study provides an example of how the "comparative" approach can be used for a specific region. It can be further evaluated by EPA to see if it meets its criteria and is useful for developing regulations.

The carbon accounting linkage between the source of the emission and the forest means that the potential of biomass as a renewable fuel is directly connected to the future of forest management. The development of biomass markets can have positive or negative effects on forest management and, conversely, the types of forest management practiced in the future will directly affect carbon payback periods. The sensitivity analysis from this study and results from other studies indicate that payback periods for biomass can vary widely depending on critical variables.

This suggests that a more comprehensive, sophisticated, and targeted approach for biomass policy that includes forest management could produce shorter payback periods and greater climate change benefits. Some potential policy targets include the following.

More Efficient Technologies

Use of biomass for thermal and CHP applications yield far shorter payback periods and greater benefits than power generation. Thermal and CHP applications can be 70-80 percent efficient while biomass power is only 25 percent efficient. Where appropriate, policy can direct forest biomass for use in these applications.

Smaller-Scale Applications

Smaller-scale heat or CHP applications can minimize transportation costs and target localized forest supply from forest situations that yield a shorter payback period. For example, localized supply of downed material or fire-prone material destined for quick carbon release to the atmosphere might show favorable payback periods if used to displace fossil fuel use for production of efficient thermal energy.

Enhanced Ecosystem Services

Biomass markets that allow forest improvement practices to protect water quality or increase carbon sequestration may improve ecosystem services that have an accompanying carbon benefit, thus lowering payback periods.

Improved Forest Management

Necessary forest-restoration work, perhaps to shift forest types to better adapted species or conduct pre-commercial thinnings, can be facilitated by biomass markets. The improved forestry can yield more forest products that offset other, more carbon-intensive products or increased revenue yields that help landowners keep forests as forests.

This study focuses on the carbon implications of increased biomass use and does not deal directly with other ecological impacts. Any policy encouraging the increased use of biomass must also account for effects on ecological values of the forest and should enhance the quality of forest management. The study results indicate a lowering of the average amount of carbon in the forest as compared to not harvesting these forests for biomass. More information is needed to fully evaluate the effects of lower carbon levels on wildlife and forest systems dynamics, including soil and water quality. An extension of best management practices to include biomass retention and harvesting guidelines is recommended. The Forest Guild has completed a set of retention and harvesting guidelines for the Northeast and is due to release a similar report for the Southeast by the end of this year.

ENDNOTES

1 Disclaimer: We did not address agricultural residues such as corn stover, wheat straw, or manure. Furthermore, the study did not factor spent black liquor from pulping, bio-solids from waste-water treatment plants, or landfill gas, even though these materials may be vital resources that could contribute toward achieving target amounts of biomass energy in the RPSs.

2 During the course of the literature search, numerous presentations and testimonies were found on-line and many of these presentations contained helpful information. However, these sources were not directly included as part of our literature review and critique because it is often very easy to take information contained in PowerPoint presentations out of context and misinterpret the meaning.

3 Chip prices are for residual chips delivered to pulpmills and do not reflect the prices of chips sourced from chipmills.

4 These model runs employed different rates of harvest residue utilization reaching upward to 85% over time.

5 This technical potential estimate uses 85% harvest residue recovery rate for softwoods and 70% for hardwoods. These recovery rates are generally considered to be on the high end of the range of what is viable.

6 It should also be noted that this resource assessment not only included North Carolina but also border counties of Virginia and South Carolina counties that fall within Duke or Progressive Energy's service territories.

7 Based on the assumption of a 50% harvest residue recovery rate.

8 Consistent but not necessarily the most accurate! While different studies may have presented more recent estimates using more sophisticated methods, these studies did not address all seven of the states and so a single data source providing "wall-to-wall" coverage was necessary.

9 In-growth (new trees) + Accretion (growth of existing trees) – Mortality (natural death) = Net growth

10 All data obtained from published FIA factsheets for each of the seven states.

11 This information on inventory comes from the USDA Forest Service's Forest Inventory and Analysis (FIA) program, which generates reliable estimates of the condition and health of the forest resource and how it is changing over time. The program uses a statistically designed sampling method to select hundreds of plots for measurement by field crews and includes plots that were counted in previous inventories. The re-measurements on the same plots yield valuable information on how individual trees grow. Field crews also collect data on the number, size, and species of trees, and the related forest attributes.

12 Data for Total Inventory is for growing stock volume. Growing stock is the traditionally merchantable wood contained in live trees greater than five inches.

13 The amount of wood derived from trees that would be otherwise used by Virginia lumber and pulp manufacturers is capped at 1.5 million green tons annually.

14 Note that each year's percentage requirement refers to the previous year's electricity sales (i.e., the 2021 standard is 12.5% of 2020 retail sales).

15 Other Renewables includes biogenic municipal solid waste, wood, black liquor, other wood waste, landfill gas, sludge waste, agriculture byproducts, other biomass, geothermal, solar thermal, photovoltaic energy, and wind.

16 Other gases includes blast furnace gas, propane gas, and other manufactured and waste gases derived from fossil fuels.

17 Other includes non-biogenic municipal solid waste, batteries, chemicals, hydrogen, pitch, purchased steam, sulfur, tire-derived fuels and miscellaneous technologies.

[18] MW electric produces approximately 136 MMBtu/hr of heat. Residential heating typically uses 40 Btu's/sq ft. Based on a 3,000 square foot house, heating requirement is 120,000 Btu's/hr, or 1,137 homes.

[19] Graph information is derived from Appendix A. See that Appendix for data and sources.

[20] Chart information is derived from Appendix A. See that Appendix for sources.

[21] Graph information is derived from Appendix A. See that Appendix for data and sources.

[22] Chart information is derived from Appendix A. See that Appendix for sources.

[23] Graph information is derived from Appendix A. See that Appendix for data and sources.

[24] Chart information is derived from Appendix A. See that Appendix for sources.

[25] Graph information is derived from Appendix A. See that Appendix for data and sources.

[26] Chart information is derived from Appendix A. See that Appendix for sources.

[27] Graph information is derived from Appendix A. See that Appendix for sources.

[28] Chart information is derived from Appendix A. See that Appendix for sources.

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Biomass Supply and Carbon Accounting for Southeastern Forests

APPENDICES

A. Technology Pathways Database

B. Forest Growth Simulation

Appendix A

TECHNOLOGY PATHWAYS SUMMARY

		A	B	C	D	E	F	G	H	I	J
1		Technology Pathway	Main Product	Co-products	Typical Capacity	Unit	Hours of operation per year	Capacity factor %	Output MMBtu/yr	Gross Effic.	Net Effic.
2									(F)*(H)*(I)*3.412		
3	1	Exisiting woody biomass	Electricity		20	MW	8,760	100%	597,782	25.6%	25.6%
4		power plants									
5	2	New woody biomass	Electricity		50	MW	8,760	100%	1,494,456	28.2%	28.2%
6		power plants									
7	2A	Pellet exportation	Electricity		50	MW	8,760	100%	1,494,456	28.2%	28.2%
8		(European power plants)									
9	3	Co-firing power plants	Electricity		450	MW	8,760	100%	13,450,104	32.3%	32.3%
10		90% coal									(coal)
11		10% woody biomass									
12											
13	4	Woody biomass	Electricity		5	MW	8,760	100%	398,026	75.0%	28.2%
14		CHP		Thermal	248,581	MMBtu					
15				Electrical	149,446	MMBtu					
16	5	Switchgrass			50	MW	8,760	100%	1,494,456	28.2%	28.2%
17		power plants									
18	6	Co-firing power plants	Electricity		450	MW	8,760	100%	13,450,104	32.5%	32.5%
19		90% coal									(coal)
20		10% switchgrass									
21											
22	7	Switchgrass	Electricity		5	MW	8,760	100%	398,026	75.0%	28.2%
23		CHP		Thermal	248,581	MMBtu					
24				Electrical	149,446	MMBtu					
25	8	Existing coal	Electricity		450	MW	8,760	100%	13,450,104	33.0%	33.0%
26		power plants									
27	9	New coal	Electricity		600	MW	8,760	100%	17,933,472	36.3%	36.3%
28		power plants									
29	10	Coal	Electricity		5	MW	8,760	100%	339,649	75.0%	33.0%
30		CHP		Thermal	190,203	MMBtu					
31				Electrical	149,446	MMBtu					
32	11	New natural gas			800	MW	8,760	100%	23,911,296	42.0%	42.0%
33		power plants									

	K	L	M	N	O	p	Q	R	S	T	U	V	W	Z	Y	Z	AA	AB
1	Heat Input MMBtu/yr	Heating value Btu/dry unit	Tons (dry) per year	Fuel Requirements lbs (dry) /MMBtu output heat	CO_2 Emissions lbs/MMBtu input heat (power production)	CO2 Emissions lbs/MMBtu input heat (production & transport)	CO_2 Emissions lbs/MMBtu input heat (total)	CO_2 Emissions lbs/MMBtu output heat (power production)	CO2 Emissions lbs/MMBtu output heat (production & transport)	CO_2 Emissions lbs/MMBtu output heat (total)	N2O Emmissions lbs/MMBtu input heat	N2O Emmissions lbs/MMBtu output heat	C equi. Emissions lbs/MMBtu input heat (power production)	C equi. Emissions lbs/MMBtu input heat (production & transportation)	C equi. Emissions lbs/MMBtu input heat (total)	C equi. Emissions lbs/MMBtu output heat (power production)	C equi. Emissions lbs/MMBtu output heat (production & transport)	C equi. Emissions lbs/MMBtu output heat (total)
2	(J)/(K)		(M)/(N)	(O)/(J)	(O)*3.6667/(M)	(J)*(U)/M	(Q)+(R)	(Q)*(M)/(J)		(T) + (U)		(W)*(M)/(J)	(Q)/3.6667	(R)/3.6667	(Y)+(Z)	(T)/3.6667	(U)/3.6667	(AB)+(AC)
3	2,335,088	8,500	137,358	459.56	215.7	4.2	219.9	842.5	16.5	859.1	0.007054	0.0276	58.8230	1.1555	59.9785	229.7775	4.513481829	234.2910
4		(btu/lb)																
5	5,307,017	8,500	312,177	417.78	215.7	4.7	220.3	765.9	16.5	782.5	0.007054	0.0250	58.8230	1.2710	60.0940	208.8887	4.513481829	213.4021
6		(btu/lb)																
7	5,307,017	8,500	312,177	417.78	215.7	68.8	284.5	765.9	244.4	1010.3	0.007054	0.0250	58.8230	18.7691	77.5922	208.8887	66.65164706	275.5403
8																		
9	5,253,947	8,500	309,056	45.96	215.7	0.4	216.1	84.3	1.7	85.9	0.007054	0.0028	58.8230	0.1155	58.9386	22.9778	0.451348183	23.4291
10	37,523,539	12,500	1,500,942	223.19	205.3	6.2	211.5	572.8	19.2	591.9	0.003306	0.0092	55.9904	1.6849	57.6753	156.2038	5.222743259	161.4266
11	42,777,486	12,100	1,809,997	269.14	206	6.6	212.9	656.3	20.8	677.1	0.003681	0.0117	56.2737	1.8004	58.0741	178.9760	5.674091442	184.6501
12																		
13	530,702	8,500	31,218	156.86	215.7	6.1	221.7	287.6	8.1	295.6	0.007054	0.0094	58.8230	1.6500	60.4730	78.4307	2.2	80.6307
14		(btu/lb)																
15																		
16	5,307,017	7,200	368,543	493.21	229.2	4.7	233.8	813.8	16.5	830.4	0.007054	0.0250	62.4995	1.2710	63.7705	221.9442	4.513481829	226.4577
17		(btu/lb)																
18	4,776,315	7,200	331,689	49.32	229.2	0.5	229.6	81.4	1.7	83.0	0.007054	0.0025	62.4995	0.1271	62.6266	22.1944	0.451348183	22.6458
19	37,228,114	12,500	1,489,125	221.43	205.3	6.2	211.5	568.2	19.2	587.4	0.003306	0.0092	55.9904	1.6982	57.6886	154.9740	5.222743259	160.1968
20	42,004,430	11,970	1,820,813	270.75	208	6.7	214.4	648.6	20.8	669.4	0.003681	0.0115	56.6413	1.8253	58.4666	176.8898	5.674091442	182.5639
21																		
22	530,702	7,200	36,854	185.19	229.2	6.1	235.2	305.6	8.1	313.6	0.007054	0.0094	62.4995	1.6500	64.1495	83.3327	2.2	85.5327
23		(btu/lb)																
24																		
25	40,757,891	12,500	1,630,316	242.42	205.3	7.0	212.3	622.1	21.3	643.4	0.003306	0.0100	55.9904	1.9150	57.9054	169.6679	5.803048066	175.4709
26		(btu/lb)																
27	49,403,504	12,500	1,976,140	220.39	205.3	7.7	213.0	565.6	21.3	586.8	0.003306	0.0091	55.9904	2.1065	58.0969	154.2435	5.803048066	160.0466
28		(btu/lb)																
29	452,865	12,500	18,115	106.67	205.3	16.0	221.3	273.7	21.3	295.0	0.003306	0.0044	55.9904	4.3523	60.3427	74.6539	5.803048066	80.4569
30		(btu/lb)																
31																		
32	56,931,657	102,800	553,809,894	23.16	117.0	33.8	150.8	278.6	80.4	359.0	0.00022	0.0005	31.9088	9.2075	41.1163	75.9733	21.92262603	97.8960
33		(btu/therm	therms	therms/MMBtu														

Grey cells are estimates

Blue cells are sourced figures

Green cells are calculations

Appendix A

D3	Average capacity of exisiting biomass plants in seven-state study region - cta.ornl.gov/bedb/biopower/Current_Biomass_Power_Plants.xls
D5, D14, D21	Average capacity of existing coal plants in seven-state study region http://www.eia.gov/electricity/data.cfm#gencapacity By Energy Source, by Producer, by State (EIA-860)XLS
D9, D18, D25	Estimate of likely size of thermal-led CHP projects feasible in seven-state study region
D23	Average capacity of coal plants constructed in seven-state study region since 2000 - http://www.eia.gov/cneaf/electricity/page/capacity/existingunits2008.xls
G3, G21, G23, G28	Average capacity factors for electrical generation plants - http://www.eia.gov/oiaf/aeo/pdf/2016levelized_costs_aeo2011.pdf
G9, G18, G25	Average capacity factor of CHP plants estimateded to be 10% lower than electrical only generation
G5, G14	Capacity factors for co-firing assumed to be the same as coal
G13	Average capacity factor of switchgrass plants assumed to be the same as woody biomass
I3, I9	Efficiencies of biomass electrical and CHP plants from IEA - Energy Technology Essentials
I21, I28	Efficiencies of coal and natural gas from EIA - Electric Power Annual 2009Released: November 23, 2011
I12, I18	Efficiencies of switchgrass plants assumed to be the same as biomass plants
J	Electrical efficiency of CHP plants assumed to be 10% lower than electrical-only effiencieny for that fuel type due to projected efficiency losses in process of heat recovery
L2, L5, L9	Assumes 0% moisture content ("bone-dry") - cta.ornl.gov/.../The_Effect_of_Moisture_Content_on_Wood_Heat_Content. Xls
L6, L15, L21, L23, L25	EIA Heating Fuel Comparison Calculator - http://www.eia.gov/neic/experts/heatcalc.xls
L12, L14, L18	Assumes 0% moisture content - Forest Product Lab Fuel Value Calculator - http://www.fpl.fs.fed.us/documnts/techline/fuel-value-calculator.pdf
O2, O5, O9	Assumes wood is 50% carbon by weight - Economics and Carbon Offset Potential of Biomass Fuels - REAP - Canada
O12, O14, O18	Assumes switchgrass is 45% carbon by weight - Economics and Carbon Offset Potential of Biomass Fuels - REAP - Canada
O6, O14, O21, O23, O25, O28	Voluntary Reporting of Greenhouse Gases Program Fuel Emissions Coefficients - http://www.eia.gov/oiaf/1605/coefficients.html
Q	Voluntary Reporting of Greenhouse Gases Program Fuel Emissions Coefficients - http://www.eia.gov/oiaf/1605/coefficients.html

Appendix B. Forest Growth Simulation.

This appendix contains information related to the forest growth, mortality and harvest simulations.

Table B-1. Prescriptions used in eco-section 231I (Central Appalachian Piedmont) for forest and regeneration types, by site class and biomass utilization. Treatment codes with associated metrics are: N=Natural regeneration in trees per acre; P=Planted in trees per acre; F-Fertilized; STS=Single Tree Selection to residual basal area (sq ft/ac); H=Herbicide treatment of competing vegetation; PT=Pre-commercial Thin to percent volume; TH=Thin from below to residual basal area (sq ft/ac); CC=Clearcut.

					Age																									
		Site (50-yr)			0		5		10		15		20		25		30		35		40		45		50		55		60		65		70	
Type	Regen	Class	Index	Biomass	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric
Loblolly/Shortleaf	Natural	Low	74	No	N										TH	80					CC													
		High	90	No	N								TH	80					CC															
		Low	74	Yes	N						PT	65%V			TH	80					CC													
		High	90	Yes	N				PT	65%V			TH	80					CC															
	Planted	Low	80	No	P,F	500	H						TH	80			TH	70			CC													
		High	102	No	P,F	550	H				TH	90			TH	70			CC															
		Low	80	Yes	P,F	700	H		PT	60%V			TH	80			TH	70			CC													
		High	102	Yes	P,F	700	H		PT	70%V	TH	90			TH	70			CC															
Pine-Oak	Natural	Low	75	No	N																												CC	
		High	94	No	N																										CC			
		Low	75	Yes	N												TH	60															CC	
		High	94	Yes	N										TH	60															CC			
Upland Hardwood	Natural	Low	78	No	STS	50			STS	50			STS	50			STS	50			STS	50			STS	50			STS	50			STS	50
		High	102	No	N																		STS	70							CC			
		Low	78	Yes	STS	50			STS	50			STS	50			STS	50			STS	50			STS	50			STS	50			STS	50
		High	102	Yes	N								TH	50									STS	70							CC			
Bottomland Hardwood	Natural	Low	86	No	N										TH	80									CC									
		High	116	No	N										TH	80							CC											
		Low	86	Yes	N						TH	80					TH	60							CC									
		High	116	Yes	N								TH	70			TH	50					CC											

Table B-2. Prescriptions used in eco-sections 232C (Atlantic Coastal Flatwoods) and 232J (Southern Atlantic Coastal Plains and Flatwoods) for forest and regeneration types, by site class and biomass utilization. Treatment codes with associated metrics are: N=Natural regeneration in trees per acre; P=Planted in trees per acre; B=broadcast burn; F-Fertilized; STS=Single Tree Selection to residual basal area (sq ft/ac); H=Herbicide treatment of competing vegetation; PT=Pre-commercial Thin to percent volume; TH=Thin from below to either residual basal area (sq ft/ac) or trees per acre (p=pine, h=hardwoods); CC=Clearcut.

					Age																													
		Site (50-yr)			0		5		10		15		20		25		30		35		40		45		50		55		60		65		70	
Type	Regen	Class	Index	Biomass	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric
Loblolly/Shortleaf	Natural	Low		No	N								TH	70			TH	60			CC													
		High		No	N						TH	85			TH	75			CC															
		Low		Yes	N		PT	400					TH	65			TH	60			CC													
		High		Yes	N		PT	450			TH	75			TH	75			CC															
	Planted	Low		No	P,F	550					TH	70			TH	60			CC															
		High		No	P,F	550					TH	80	TH	80			CC																	
		Low		Yes	P,F	550			PT	400			TH	65			TH	60	CC															
		High		Yes	P,F	550			PT	400	TH	80	TH	80			CC																	
Longleaf/Slash	Natural	Low		No	B,N								TH	70			TH	60			CC													
		High		No	B,N						TH	85			TH	75			CC															
		Low		Yes	B,N		PT	400					TH	65			TH	60			CC													
		High		Yes	B,N		PT	450			TH	75			TH	75			CC															
	Planted	Low		No	P,F	550					TH	70			TH	60			CC															
		High		No	P,F	550					TH	80	TH	80			CC																	
		Low		Yes	P,F	550			PT	400			TH	65			TH	60	CC															
		High		Yes	P,F	550			PT	400	TH	80	TH	80			CC																	
Pine-Oak	Natural	Low		No	N										TH	65p/50h					CC													
		High		No	N								TH	50p/50h			TH	45p/45h			CC													
		Low		Yes	N						TH	350p/200h			TH	70					CC													
		High		Yes	N								TH	50p/50h			TH	45p/45h			CC													
Upland Hardwood	Natural	Low		No	STS	50			STS	50			STS	50			STS	50			STS	50			STS	50			STS	50			STS	50
		High		No	N										CT	80					STS	50			STS	30					CC			
		Low		Yes	STS	50			STS	50			STS	50			STS	50			STS	50			STS	50			STS	50			STS	50
		High		Yes	N								TH	70					STS	50			STS	30							CC			
Bottomland Hardwood	Natural	Low		No	N										TH	80									CC									
		High		No	N										TH	80							CC											
		Low		Yes	N								TH	65					TH	80					CC									
		High		Yes	N								TH	70					TH	80			CC											

Table B-3. Prescriptions used in eco-section 232B (Gulf Coastal Plains and Flatwoods) for forest and regeneration types, by site class and biomass utilization. Treatment codes with associated metrics are: N=Natural regeneration in trees per acre; P=Planted in trees per acre; B=broadcast burn; F-Fertilized; STS=Single Tree Selection to residual basal area (sq ft/ac); H=Herbicide treatment of competing vegetation; PT=Pre-commercial Thin to percent volume; TH=Thin from below to either residual basal area (sq ft/ac) or trees per acre (p=pine, h=hardwoods); CC=Clearcut.

					Age																													
		Site (50-yr)			0		5		10		15		20		25		30		35		40		45		50		55		60		65		70	
Type	Regen	Class	Index	Biomass	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric
Loblolly/Shortleaf	Natural	Low		No	N								TH	70			TH	60			CC													
		High		No	N						TH	85			TH	75			CC															
		Low		Yes	N		PT	400					TH	65			TH	60			CC													
		High		Yes	N		PT	450			TH	75			TH	75			CC															
	Planted	Low		No	P,F	550					TH	70			TH	60			CC															
		High		No	P,F	550					TH	80	TH	80			CC																	
		Low		Yes	P,F	550	PT	400					TH	65			TH	60	CC															
		High		Yes	P,F	550	PT	400			TH	80	TH	80			CC																	
Longleaf/Slash	Natural	Low		No	B,N								TH	70			TH	60			CC													
		High		No	B,N						TH	85			TH	75			CC															
		Low		Yes	B,N		PT	400					TH	65			TH	60			CC													
		High		Yes	B,N		PT	450			TH	75			TH	75			CC															
	Planted	Low		No	P,F	550					TH	70			TH	60			CC															
		High		No	P,F	550					TH	80	TH	80			CC																	
		Low		Yes	P,F	550	PT	400					TH	65			TH	60	CC															
		High		Yes	P,F	550	PT	400			TH	80	TH	80			CC																	
Pine-Oak	Natural	Low		No	N										TH	65p/50h					CC													
		High		No	N								TH	50p/50h			TH	45p/45h			CC													
		Low		Yes	N						TH	350p/200h			TH	70					CC													
		High		Yes	N								TH	50p/50h			TH	45p/45h			CC													
	Planted	Low		No	Pl pine	500									TH	65p/50h					CC													
		High		No	Pl pine	300							STS	50p/50h			STS	45p/45h			CC													
		Low		Yes	Pl pine	500					TH	350p/200h			TH	70					CC													
		High		Yes	Pl pine	300							TH	50p/50h			TH	45p/45h			CC													
Upland Hardwood	Natural	Low		No	STS	50			STS	50			STS	50			STS	50			STS	50			STS	50			STS	50			STS	50
		High		No	N										CT	80					STS	50			STS	30					CC			
		Low		Yes	STS	50			STS	50			STS	50			STS	50			STS	50			STS	50			STS	50			STS	50
		High		Yes	N								TH	70					STS	50			STS	30							CC			
Bottomland Hardwood	Natural	Low		No	N										TH	80									CC									
		High		No	N										TH	80							CC											
		Low		Yes	N								TH	65					TH	80					CC									
		High		Yes	N								TH	70					TH	80			CC											

Table B-4. Age class distribution by forest type, regeneration type, and site class for eco-section 231I (Central Appalachian Piedmont).

			Age																										
Type	**Regen**	**Site Class**	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120	125	130
Loblolly/Shortleaf	Natural	Low	0	9	29	26	29	24	27	21	13	27	26	21	17	13	11	5	4	2	1	2	0	0	0	0	0	0	0
		High	0	2	3	2	3	9	13	4	9	14	11	8	6	6	4	1	3	0	0	0	0	0	0	0	0	0	0
	Planted	Low	0	48	67	49	42	49	38	19	12	6	3	3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		High	0	3	2	9	10	18	16	5	5	2	2	3	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
Pine-Oak	Natural	Low	1	14	23	18	17	23	19	24	16	21	12	11	13	18	21	8	11	3	3	0	3	0	0	1	0	0	0
		High	0	2	0	1	3	2	5	6	6	9	4	4	3	7	2	0	2	1	1	0	0	0	0	0	0	0	0
Upland Hardwood	Natural	Low	3	94	80	83	47	41	58	55	57	80	79	94	89	95	76	69	65	50	36	15	23	15	11	1	1	2	0
		High	0	11	3	5	4	7	10	7	7	10	8	11	10	13	5	2	1	6	4	0	1	0	1	0	0	0	1
Bottomland Hardwood	Natural	Low	0	4	8	10	3	10	4	8	6	11	13	14	13	9	7	9	11	3	2	1	0	2	0	1	0	0	0
		High	0	0	0	0	2	2	2	3	2	1	2	0	1	1	2	1	0	0	0	0	0	0	0	0	0	0	0

Table B-5. Non-sprouting regeneration data for loblolly-shortleaf pine plantations in eco-section 231I (Central Appalachian Piedmont). Since loblolly is planted it will not be naturally regenerated for the planation simulation.

Species	FIA_Code	FVS_Code	Sprout (1=yes)?	Trees/ac.	DBH (in)	Ht (ft)	CR (%)
eastern redcedar	68	OS	0	6.4	1.7	17	72
loblolly pine	131	LP	0	103.4	2.9	22	41
mockernut hickory	409	OH	0	4.2	1.7	22	41
pignut hickory	403	OH	0	2.7	1.7	23	51
shagbark hickory	407	OH	0	0.3	1.5	20	35
shortleaf pine	110	SP	0	0.5	4.6	34	34
Virginia pine	132	VP	0	23.0	2.4	21	36
willow oak	831	OH	0	2.5	2.5	24	38
river birch	373	OH	0	0.3	2.3	37	25

Table B-6. Non-sprouting regeneration data for natural upland hardwood stands in eco-section 231I (Central Appalachian Piedmont).

Species	FIA_Code	FVS_Code	Sprout (1=yes	Trees/ac.	DBH (in)	Ht (ft)	CR (%)
eastern hemlock	261	OS	0	0.1	1.0	12	90
eastern redcedar	68	OS	0	5.1	2.3	20	53
eastern white pine	129	WP	0	1.3	2.2	17	46
loblolly pine	131	LP	0	2.7	3.1	24	36
mockernut hickory	409	OH	0	2.3	2.4	27	37
pignut hickory	403	OH	0	4.4	2.4	26	34
shagbark hickory	407	OH	0	0.3	2.1	25	33
shortleaf pine	110	SP	0	0.2	3.9	45	28
Virginia pine	132	VP	0	3.6	2.5	22	32
willow oak	831	OH	0	0.9	2.0	24	49
river birch	373	OH	0	0.1	2.4	25	55
mountain or Fraser magnolia	655	OH	0	0.2	1.2	16	55
umbrella magnolia	658	OH	0	0.5	2.3	24	29
bitternut hickory	402	OH	0	0.5	2.4	30	22
red mulberry	682	OH	0	0.1	3.6	32	45
pitch pine	126	PP	0	0.2	3.4	21	30
American basswood	951	OH	0	0.2	3.7	34	35

BERC

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