WORKING PAPER

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

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the Nicholas Institute

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EXECUTIVE SUMMARY

The following report evaluates the implications of biomass use at multiple levels of demand and under various policy scenarios across the southeastern United States. It represents the culmination of a four-month joint research effort between North Carolina State University, the Nicholas Institute for Environmental Policy Solutions at Duke University, and Environmental Defense Fund. It provides background on the methodology used to conduct the analysis, as well as an overview of an associated Biomass Demand Interface Tool that can be used to view the results. Collectively, these allow for the simultaneous evaluation of dozens of demand scenarios on multiple metrics of concern, thus providing the beginnings of a comprehensive overview of the range of impacts that increasing demand for forest biomass may have in a given state or region.

BACKGROUND

In recent years, multiple studies have attempted to gauge the social, economic, and environmental impact of specific levels of increased biomass demand in the southeastern United States (Abt et al. 2010a; Abt et al. 2010b; Galik et al. 2009). Feasibility assessments of meeting specific biomass utilization targets have likewise been conducted at the national level (Perlack et al. 2005; Energy Information Administration 2007; Pinchot Institute for Conservation and The Heinz Center 2010). These assessments have been informative in the potential effects of increased use of forest biomass for the scenarios they consider, but questions remain as to the larger trends and tradeoffs experienced across a wider variety of levels of biomass demand. For example, research may show that a 25% Renewable Fuel Standard (RFS) and 25% Renewable Electricity Standard (RES) may have a certain effect on biomass prices, harvest activity, and fuel mix, but may be much less relevant should policymakers consider a 20% RFS/RES scenario.

This assessment attempts to broaden the understanding of forest biomass use across a much wider range of potential demand scenarios. Specifically, we consider the implications of forest biomass use across multiple levels of biomass demand and under multiple environmental and economic constraints. The evaluation begins with an assessment of Georgia, North Carolina, and South Carolina, but could be replicated for many other states across the Southeast. For each state examined, we assess forest condition, carbon balance, and feedstock price and supply at various levels of demand and under multiple sourcing restrictions. We then compare these demand and constraint scenarios against a baseline, business-as-usual (BAU) scenario to estimate changes in forest and market conditions over time. Initial results for Georgia, North Carolina, and South Carolina are briefly discussed here, and are available for detailed evaluation in the attached biomass tool.

METHODS AND SCOPE

This analysis builds upon previous research on the effects of increased forest biomass demand. We use the SubRegional Timber Supply (SRTS) model to evaluate the supply-side impacts of multiple levels of biomass demand. Assumptions and methodology relevant to this particular study are described below, but greater background on the general approach used to evaluate the effects of increased demand for forest biomass, generally, can be found in Abt et al. (2010a), Abt et al. (2010b), and Galik et al. (2009). Further discussion of the SRTS model itself can be found in Abt et al. (2009) and Prestemon and Abt (2002).

Demand Scenarios

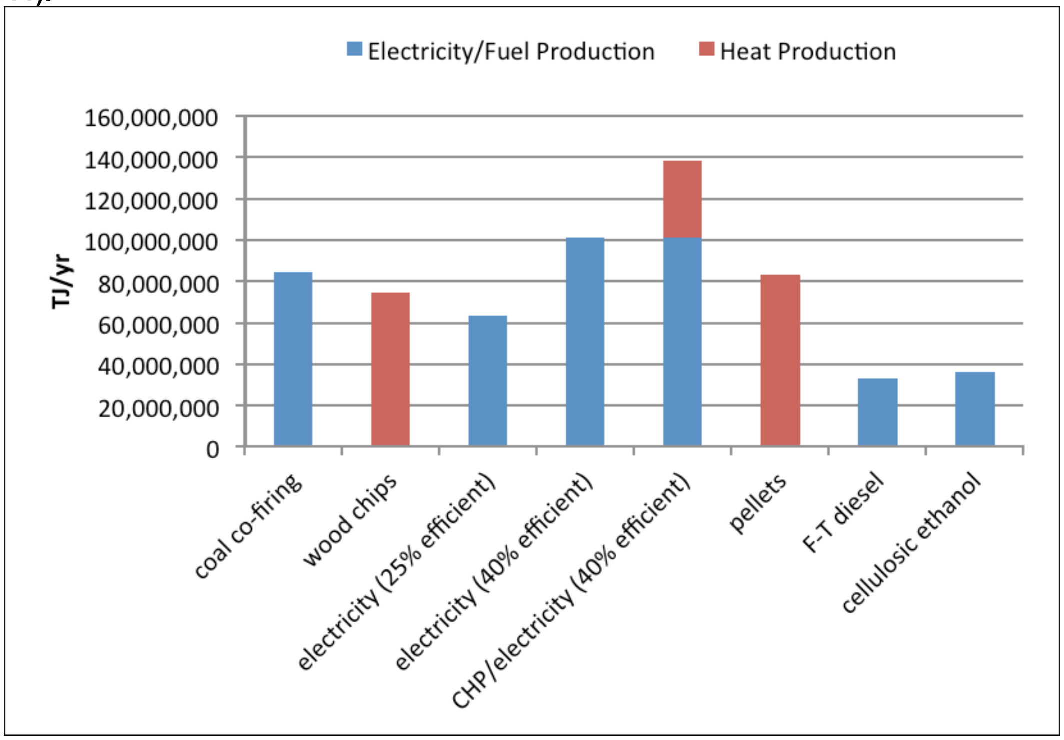
Several sources were used to estimate the annual demand for biomass to meet various renewable transportation fuel and electricity production targets. This array of fuel and electricity targets formed the basis of the matrix against which effects on multiple environmental and economic indicators were evaluated. Conceptually, the matrix can be pictured as having a range of RES targets along the top and a series of RFS targets along the side (Table 1). In actuality, however, the demand associated with each policy combination is not a single number, but rather an estimate of annual demand for biomass for transportation fuel and electricity production that itself varies over time from the first year of our study period, 2010, through its conclusion in 2030. The annualized woody biomass demand under each scenario for each state, as well as the underlying calculations, can be found in Appendix A and B.

Table 1. Matrix of demand for woody biomass as influenced by varying renewable electricity standard (RES) and renewable fuel standard (RFS) intensities. Cells indicate the demand associated with specific policy scenario combinations.

		RES targets for woody biomass consumption					
		0.0%	1.0%	2.5%	5.0%	7.5%	10%
Percentage of the expected contribution of woody biomass to the RFS2 that is actually met	0%	RFS0% + RES0%	RFS0% + RES1%	RFS0% + RES2.5%	RFS0% + RES5%	RFS0% + RES7.5%	RFS0% + RES10%
	50%	RFS50% + RES0%	RFS50% + RES1%	RFS50% + RES2.5%	RFS50% + RES5%	RFS50% + RES7.5%	RFS50% + RES10%
	75%	RFS75% + RES0%	RFS75% + RES1%	RFS75% + RES2.5%	RFS75% + RES5%	RFS75% + RES7.5%	RFS75% + RES10%
	100%	RFS100% + RES0%	RFS100% + RES1%	RFS100% + RES2.5%	RFS100% + RES5%	RFS100% + RES7.5%	RFS100% + RES10%
	125%	RFS125% + RES0%	RFS125% + RES1%	RFS125% + RES2.5%	RFS125% + RES5%	RFS125% + RES7.5%	RFS125% + RES10%
	150%	RFS150% + RES0%	RFS150% + RES1%	RFS150% + RES2.5%	RFS150% + RES5%	RFS150% + RES7.5%	RFS150% + RES10%

The amount of biomass needed to meet a particular energy or fuel production target is of course highly dependent on the application (e.g., transportation fuel, process heat, electricity production), pathway (e.g., pellet production and combustion versus co-firing, cellulosic ethanol production versus Fischer-Tropsch diesel), and conversion efficiency. Indeed, several recent studies have highlighted these differences and the effect they may have on energy substitution and GHG emission reduction objectives (Campbell et al. 2009; Buchholz et al. 2011; Manomet Center for Conservation Sciences 2010). Generally consistent across these and other studies is a fairly wide divergence in the energy potential from a given level of biomass depending on how it is used, with combined heat and power (CHP) and process heat applications often displaying among the greatest potential and production of liquid transportation fuels among the least. An example of this in the context of woody biomass use in the northeastern United States can be seen in Figure 1, in which total energy production potential from a set amount of biomass varies depending on the application and pathway.

Figure 1. Woody biomass energy production potential in eight northeastern states as a function of the application used to produce it. Note that the total amount of potential energy production varies significantly depending on the application and pathway used to produce it (from Buchholz et al. 2011).



This relationship between biomass energy production potential and the pathway by which it is produced is critical in our assessment of biomass demand. This is because the analysis here, as well as the Biomass Demand Interface Tool that accompanies it, is based on the amount of woody biomass needed to satisfy particular electricity and liquid transportation fuel production targets. Varying the efficiency by which these electricity and fuel targets are met has strong implications for the volume of biomass needed. As such, the analysis here should be thought of as representing one of many possible energy production scenarios; different pathway and application assumptions will likely yield different levels of biomass demand than estimated here.

Renewable Electricity Demand

Electricity demand for the three states evaluated here was derived from Appendix G, Calculations for State Profiles in Brown et al. (2010). Brown et al. (2010) contain estimates for electricity demand from commercial, residential, and industrial sectors for each state assessed here across the entire study period. These estimates of sectoral electricity demand are themselves derived from U.S. Department of Energy—Energy Information Administration regional projections, partitioned to individual states through a combination of census projections and historical per capita energy consumption (see Brown et al. [2010], p. 28 for more information). Also included in Brown et al. are estimates of line loss which, when added to estimates for total electricity demand, provide an estimate of the total net electricity that must be produced in a given year. It is these estimates of total electricity production that are used as the basis for demand projections here; the assumed RES percentage is simply applied to total electricity production for a given year to determine the expected contribution of woody biomass for that year.[1] To approximate the likely trajectory of adoption and/or compliance requirements, we assume that the RES is increased by 10% annually until reaching the target allocation in year 2019. A conversion rate of 8,500 BTU per bone dry pound of biomass is used to convert the resulting level of electricity production into tons (Appendix A).

To provide context to the scale of biomass demand as a percentage of total sales, the values considered here can be compared to those few existing state Renewable Portfolio Standard (RPS) programs that include internal biomass targets, or "carve-outs." For example, Connecticut, New Hampshire, and New Mexico do establish either specific carve-outs for biomass or a carve-out for a larger class of sources of which biomass is included (DSIRE 2010). In Connecticut, biomass power is eligible to contribute to either Class I or Class II RPS targets, depending on the type of facility, targets that rise over time to a maximum of 20% and 3% of total retail load in 2020 for Class I and Class II sources, respectively. New Mexico requires that 2% of total sales, or 10% of RPS, come from geothermal, biomass, some types of hydropower facilities, and other renewable energy sources. Alternatively, New Hampshire includes a specific carve-out for existing biomass facilities, peaking at 6.5% in 2011 and continuing through 2025.

Renewable Fuel Demand
The emerging nature of liquid transportation fuel production from cellulosic feedstock such as woody biomass makes an approach similar to the electricity portion—where total electricity production is estimated into the future and allocated to individual states based on census data and historical trends—difficult in the case of RFS demand projection. With only one commercial-scale, woody biomass–fed cellulosic ethanol refinery either under construction or in operation in the study area, it is impossible to project future production at the state level from existing capacity.

The presence of a binding liquid transportation fuel mandate, however, provides another potential mechanism for estimating potential demand. This is the approach used here, in which total demand for woody biomass for transportation fuel production is derived from estimates of woody biomass contributions to the expanded federal RFS (or "RFS2") established in the 2007 Energy Independence and Security Act. This is combined with estimates of forest residue availability in each of the three states studied here to estimate expected state-level contributions to the federal target over time.

The USDA RFS2 Roadmap (U.S. Department of Agriculture 2010) estimates that up to 2.8 billion gallons of cellulosic ethanol could be produced from forest residues in 2022. With no indication as to how this total production is to be allocated to individual states, other estimates of forest biomass availability were examined to estimate each state's share of total production. Using the state-level estimates of forest residue availability contained in Milbrandt (2005), national production potential is approximately 3.05 billion gallons per year (bgy), assuming 70 gallons of fuel per bone dry ton. Although 3.05 bgy exceeds the estimate of 2.8 bgy cited by USDA, the relative proximity of the two suggests that parsing out individual state contributions to total demand for liquid transportation fuel production based on the Milbrandt (2005) residues numbers could represent a reasonable approximation.[2] In doing so, we estimate total year-2022 production of woody biomass–derived liquid transportation fuel to be 249 million gallons per year (mgy) in Georgia, 210 mgy in North Carolina,[3] and 121 mgy in South Carolina. To put these

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[1] Although most state RPS/RES programs outline compliance targets as a percentage of *sales*, adding in line losses will provide an estimate of how much renewable energy must be *produced* (and by extension, how much biomass must be supplied) to achieve this net result.
[2] Note that we are interested in examining the impact of biomass demand on both whole tree and harvest residue resources. We use estimates of residue availability in Milbrandt (2005) simply for the purposes of establishing some sense of relative magnitude of biomass contributions to the federal target.
[3] In the case of North Carolina, this annual production level is well below the Biofuels Center of North Carolina's strategic target of 600 mgy by 2017, though not all of this level of production need come from woody biomass. Even so, the estimated level of

numbers in the context of the demand matrix in Table 1, a RFS2 row value of "100%" assumes that these volumes are met in full, a value of "50%" that only half these volumes are produced, and so forth.

Our assumption is that the RFS2 is the primary driver for cellulosic biofuel production in the near- to mid-future, so we assume that these fuel production amounts remain static upon reaching maximization of the RFS2 in 2022. Since there are no commercial scale woody biomass-to-transportation fuel facilities currently in operation, production is assumed to scale up along a 10-year logistic curve from zero gallons of production in 2011 to the target amount for each state in 2022.[4] The percentage of this expected contribution to the RFS2 target is then varied to establish a range of demand scenarios (Appendix B).

Potential Greenhouse Gas Effects

To gauge the approximate greenhouse gas (GHG) effects of substituting biomass for fossil fuel–derived electricity, we first estimate state-specific emission factors using the U.S. Environmental Protection Agency's eGRID database (U.S. Environmental Protection Agency 2008). We assume here that biomass would be used to substitute for coal, either by co-firing with coal in existing boilers or by burning instead of coal in new, dedicated boilers. Accordingly, we base our emission factor estimates on only those boilers with BIT (bituminous coal), LIG (lignite coal), SC (synthetic coal, or syncoal), and SUB (sub-bituminous coal) listed as their primary boiler fuel. This yields state-specific emission reduction coefficients of 89.39, 90.98, and 86.04 kg carbon dioxide equivalent (CO_2e)/MMBTU for Georgia, North Carolina, and South Carolina, respectively.

As in previous work (Abt et al. 2010), we assume that GHG benefits accrue relative to a BAU situation if the decline in net forest carbon storage is less than a comparable reduction in fossil emissions. For both biomass- and fossil-based fuels, we do not consider shifts in transportation emissions or energy required to dry and process feedstock, or in the case of liquid transportation fuels, to produce the end-use fuel. We also do not directly estimate changes in net emissions within the study area attributable to displacement of other users of forest resources. We do, however, include a rough approximation of potential effects stemming from induced harvest activity outside of the region ("leakage"), represented here as a user-defined percentage of displaced industrial capacity.[5] Even with this added functionality, the estimates provided here should be regarded as providing only a simple first-order estimate of the potential magnitude and direction of GHG emission shifts.

As with electricity, we provide a rough estimate of net GHG balance for transportation fuels by comparing the observed shift in on-site carbon storage against potential emissions reductions. Specifically, we assume a default gasoline tailpipe emission conversion factor of 79 kg CO_2e/MMBTU (U.S. Environmental Protection Agency 2010), which is then multiplied by 75,700 BTU/gallon (Lower Heating Value, or LHV; see http://bioenergy.ornl.gov/papers/misc/energy_conv.html, Retrieved January 26, 2011) to account for the lower energy content of ethanol as compared to gasoline. This generates an emission reduction coefficient of 5.98 kg CO_2e/gallon of ethanol produced. As above, we do not consider the emissions associated with the production of either fossil or alternative fuels, focusing instead on the approximate effects on forest carbon and changes in end-use fossil emissions.

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biofuel production assumed here is still significantly lower than the eventual 490 mgy of woody biomass–derived biogasoline and ethanol production envisioned in a 2010 economic impact analysis (Biofuels Center of North Carolina 2010).

[4] While we acknowledge the practical challenges of meeting this expected level of production, especially in the early years of the scenarios given the shortage of facilities currently in operation or under construction, interim advanced biofuel targets established by the RFS2 do require increasing levels of cellulosic biofuel production beginning in 2009. EPA may issue compliance waivers in situations where these annual targets cannot be met, but we think it important to nonetheless examine the impact of the policy as outlined in legislation.

[5] For example, if a given scenario results in 100,000 green tons of displacement, net GHG emissions may be tempered by a percentage of the 83,166 metric tons CO_2e embodied in that wood (100,000 green tons ÷ 2 [assuming 50% water weight per green ton] ÷ 2 [assuming carbon comprises 50% dry weight] * 3.667 [tons of CO_2e per ton of C] = 91,675 U.S. tons, or 83,166 metric tons).

Habitat Restrictions

Among the multiple constraints considered on the supply side are the effects of habitat restrictions. Current biofuels policy contains a variety of restrictions on where biomass may be sourced. For example, the 2007 Energy Independence and Security Act limits prohibits biofuels made from biomass sourced from forests ranked as critically imperiled, imperiled, or rare under a state Natural Heritage Program from meeting certain provisions of the RFS2 established in that bill. Likewise prohibited are biofuels produced from biomass sourced from old growth or late successional forests (P.L. 110-140; Secs. 201(1)(I) and 202). A significantly more open definition was included in the Food, Conservation, and Energy Act of 2008 (P.L. 110-246; Sec. 9001[12]) for the purposes of determining which feedstocks qualify for various biofuel and renewable energy grants, however. Concerns linger amid the resulting uncertainty over the potential impacts of an expanded biomass market on wildlife habitat and other environmental amenities.

These habitat restrictions are included in our modeling of biomass supply dynamics primarily through the withdrawal of potential harvestable inventory. The methods by which this volume is withdrawn is consistent for each state in the study region, but the underlying data used to determine the area and volume of withdrawal does vary from state to state. An important point is that we do not actually target specific areas for exclusion, but rather use the *attributes* of those areas to moderate the available supply from the larger survey units.

To estimate the area and attributes for withdrawal, data were first acquired for each state that captured areas of special conservation value, be it for wildlife habitat, water quality, aesthetics, recreation, or other social or environmental values (Table 2). Because current versions of SRTS source biomass from only those forest lands not already withdrawn from use, we excluded all state and federally owned lands from our analysis, as it is assumed that no biomass would have been sourced from these lands by the model to begin with. To capture the effect of conservation lands held by private individuals, nonprofits, and local and municipal entities, we utilized the data listed in Table 2 to tabulate the area of four land use/cover types found within each protected area, by FIA survey unit.

Table 2. Data used to evaluate the influence of sourcing restrictions on woody biomass supply dynamics. Source and description are indicated for each.

State	Data Layer	Description	Source
Georgia	Conservation Lands 2009	Areas currently managed by state, local, and private entities for conservation purposes.	Georgia Department of Natural Resources, WRD Nongame Conservation Section; https://data.georgiaspatial.org//index.asp
North Carolina	Lands Managed for Conservation and Open Space	Areas managed by public and/or nonprofit entities for scenic, recreational, conservation, historic, or other purposes.	NC Center for Geographic Information and Analysis; www.nconemap.com
South Carolina	Stewardship Lands	Areas managed for conservation purposes by federal, state, or private entities.	South Carolina Department of Natural Resources, GAP Analysis Program; http://www.dnr.sc.gov/GIS/gap/gapdata.html
(All)	Conterminous United States Land Cover, 200-Meter Resolution 1992	Raster providing land cover characteristics for conterminous United States.	National Atlas of the United States; http://nationalatlas.gov/atlasftp.html?openChapters=chpbio#chpbio

We assume that these various conservation lands would not contain any planted pine, and so limit our assessment of withdrawn areas to deciduous forest, evergreen forest, mixed forest, and woody wetlands. These are assumed to be approximations of the comparable forest types used in SRTS, or upland hardwood, natural pine, mixed pine, and lowland hardwood, respectively. We then determined the percent of total cover in each survey unit that was found within the boundaries of these potentially reserved areas, and deducted this from the available acreage in the SRTS inventory files. We assumed that the age class distribution and all other stand characteristics are the same in our protected areas and the rest of the survey unit, though we acknowledge that some differences may exist (e.g., heavier weighting of older age classes on conservation lands). At the conclusion of this exercise, we find that the removal of private, local, and municipal conservation lands account for 0% to approximately 14% of the total available land base in each forest type (Table 3).

Although these habitat screens may lead to relatively small exclusions in North Carolina, they result in more significant exclusions in Georgia and South Carolina. It would of course be possible to create scenarios in which a larger percentage was removed from North Carolina to be on par with the other two states included here, but the policy restrictions needed to achieve this consistency would likely differ from state to state. Here, we err on the side of policy consistency to demonstrate the relative impact of a similar set of restrictions across three southeastern states.

Table 3. Acreage removed from each land use type as a result of conservation restrictions, as a percentage of total available timberland.

State	FIA Survey Unit	Land Use Type			
		Deciduous	Evergreen	Mixed	Woody Wetland
Georgia	1	0.7%	1.4%	0.7%	2.1%
	2	2.2%	2.7%	4.7%	1.6%
	3	1.4%	1.4%	1.1%	1.7%
	4	1.1%	0.7%	0.8%	0.2%
	5	3.8%	3.4%	2.9%	2.3%
North Carolina	1	0.4%	1.8%	0.6%	2.8%
	2	0.2%	0.4%	0.2%	1.5%
	3	0.1%	0.2%	0.2%	0.3%
	4	0.8%	1.0%	1.1%	0.0%
South Carolina	1	0.5%	1.7%	0.9%	1.2%
	2	4.1%	5.2%	5.0%	4.5%
	3	8.1%	14.1%	9.6%	5.2%

We also evaluate the potential influence of removals from public lands on private-land biomass demand. This exercise is much simpler, in that we simply assume that observed removals from public lands form the basis for future residue removal and utilization. Specifically, we apply a set percentage to removals from U.S. Forest Service land to account for the amount of residues generated and available for harvest.[6] We assume that useable residues are 20% of harvested volume for pine and 30% of harvested volume for hardwood (Pelkki 2009; Table 4). This amount is then applied against total biomass demand, thus tempering the amount of biomass that must be harvested on all other lands. We do not evaluate the

[6] Both public and private timberland data were downloaded from the FIA website in July 2010. Data includes the 2008 panel for Georgia and the 2007 panels for North Carolina and South Carolina.

impacts of public-land removals on public-land forest characteristics, as we assume that all harvest activity is heavily managed and monitored, with a large portion of the volume coming from stewardship and restoration activities. In a similar sense, we also assume that harvest amounts do not change over time.

Table 4. Estimated annual available volume of biomass from U.S. Forest Service lands.

State	Estimated Residue Availability (green tons)
Georgia	31,928
North Carolina	18,204
South Carolina	26,042

Biomass Component

One area of focus in recent biomass policy deliberations has been the eligibility of whole-tree biomass in meeting renewable energy targets. This issue largely stems from concerns that new markets for woody biomass will encourage increasing intensity of forest management, including increased harvest activity, to meet renewable fuel and energy demands. Limiting eligible fuel sources to the byproducts of harvests conducted for other purposes, be it pulp, paper, or forest product markets; restoration; or stewardship activities, could limit the direct influence of biomass markets on the composition of the forested landscape. The opposing argument is that harvest residues are too few, too inconsistent, and too costly to support a meaningful level of energy or fuel production in and of themselves.

Front and center in this debate is the state of North Carolina, in which a recent Utilities Commission finding specified that whole tree–derived wood fuel would qualify for contribution towards state RPS requirements (NC Utilities Commission 2010). Although the NC RPS specifically lists wood waste as one of several fuel sources that may be included in the definition of biomass resources eligible to contribute towards RPS compliance, the definition is silent on the role of purpose-harvested, whole tree–derived energy (G.S. 62-133.8[a][8]). In the process of evaluating the issue, multiple entities weighed in both for and against the inclusion of whole tree–derived fuel within the definition of a biomass resource, and the decision attracted significant local and trade media attention (e.g., Forest2Market 2010; Henderson 2010).

To operationalize this portion of the analysis, we simply allow the model to freely source biomass under a "whole tree" assumption, while limiting available supply to accessible harvest residues under a "residues only" scenario. In this context, "whole tree" simply refers to a situation in which the removal and use of the entire tree for biomass fuel or energy purposes is permitted. Thus both harvest residues and roundwood components are available for renewable energy or transportation fuel applications. Alternatively, the "residues only" scenario assumes that the high demands placed on biomass will encourage greater harvest efficiency, resulting in a maximum achievable rate of residues harvest of 67% of available material,[7] as opposed to a maximum efficiency of 50% in the "whole tree" scenarios. To account for adoption and technological improvement over time, we scale up residue utilization efficiency from zero to the maximum efficiency along a 10-year logistic curve, reaching peak efficiency in 2021.[8] We assume that no shift in what is defined as a harvest residue occurs across this timeline, and that harvest activities are not altered to maximize the availability of residues. Under the "residues-only" scenarios, we therefore expect the primary consideration to be whether or not specific fuel and energy targets can be met, as harvest and forest land use patterns do not change.

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[7] Perlack et al. (2005) cite multiple harvest efficiencies in their review of biomass supply potential. 67% is higher than current reported utilization efficiency, but well below that reported from use of integrated harvest systems. Accordingly, the estimate can be thought to represent a situation in which there is an incentive to increase the efficiency of residue harvest beyond what is currently practiced in the field.

[8] Some degree of harvest residues are currently being utilized, thus our assumption of a 0% starting point may overestimate the amount of residues available for use in new fuel or electricity generation applications at any given efficiency.

OUTPUT, OBSERVATIONS, AND CONCLUSIONS

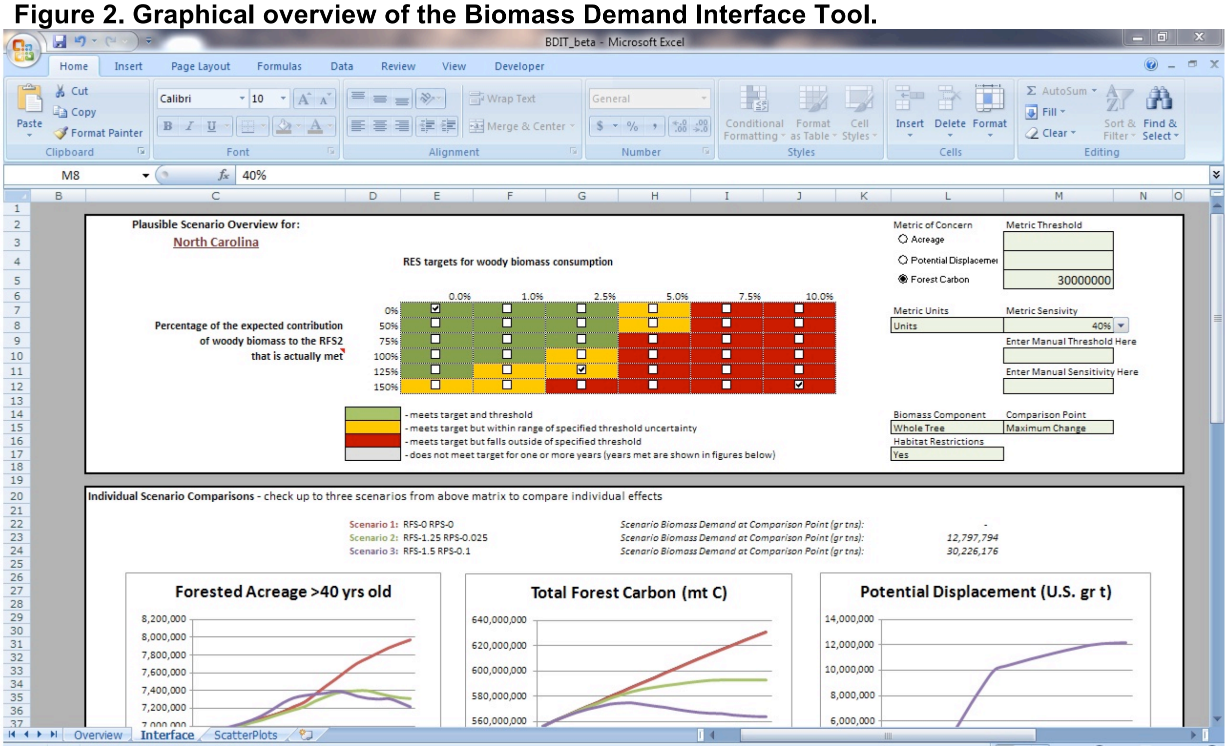
The various constraints and demand scenarios discussed above yield a combined total of 144 unique biomass model runs for each state. Collectively, the results suggest that it is technically possible to meet all levels of demand considered here when using whole tree–derived biomass, but that most demand scenarios fail to meet established targets for at least some years when limiting biomass to harvest residues. The associated Biomass Demand Interface Tool can be used to further evaluate the trends and tradeoffs associated with various levels of biomass demand and harvest restrictions in each state.

Biomass Demand Interface Tool

The Tool provides two types of graphical overviews (Figure 2). The first is a summary matrix that contains information on the relative performance of all biomass demand scenarios in one of three key issue areas: shift in forest age, change in forest carbon, and potential incidence of displacement. The second allows for detailed comparison of up to three individual scenarios in these same key issue areas over time. Individual scenarios may also be evaluated for their effect on total forested acreage, scenario net GHG emissions, and pine pulpwood prices.

The summary matrix contains information on how a particular demand scenario performs relative to the threshold criteria set by the user. Once the user selects the state, biomass component, level of habitat restriction, a metric, a threshold for that metric that should not be exceeded, and a level of uncertainty to bound that threshold, the matrix provides a color-coded indication of whether a particular demand scenario meets both its established target and threshold. Several preset thresholds are included in the Tool, encapsulating a full range of impacts for each metric, though manual thresholds may also be set. The same is true for uncertainty thresholds.

Figure 2. Graphical overview of the Biomass Demand Interface Tool.



Once the user makes the necessary selections, the matrix indicates a scenario's performance relative to the criteria set for it. If a cell corresponding to particular demand scenario is green, the scenario meets both the demand target and satisfies the selected threshold. If the cell is yellow, the scenario meets the target but falls within the range of specified threshold uncertainty. If the cell is red, the scenario meets the target but falls outside of the specified threshold. Finally, if the cell is grey, the scenario does not meet the target for one or more years.

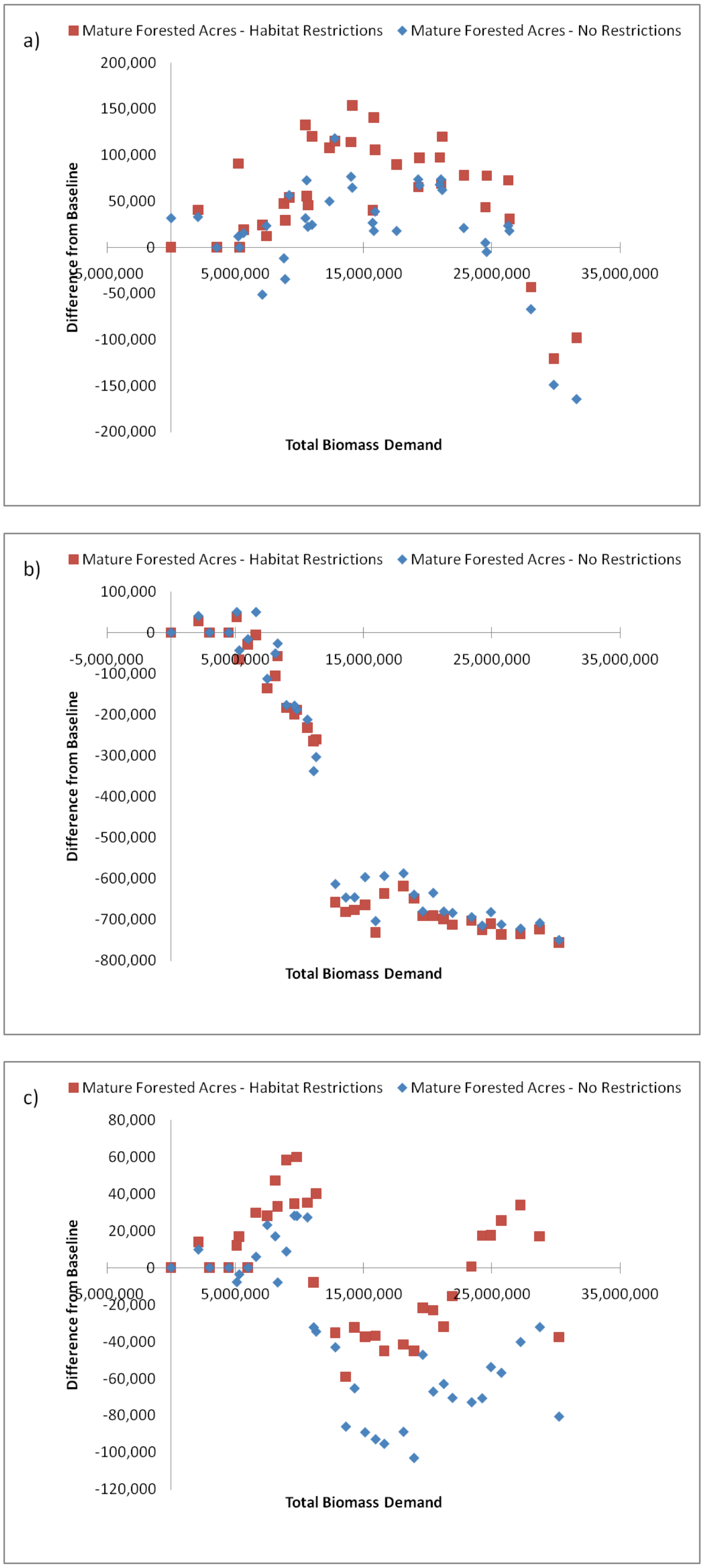
The individual scenario comparison figures show the annual performance of up to three selected scenarios. The user simply selects the corresponding check box for the desired scenario in the summary matrix. The scenario name, as well the specific amount of biomass demanded at the chosen comparison point (e.g., 2020, 2030, an Average Annual amount, etc.), is then indicated in the lower portion of the Tool. Note that the biomass component and habitat restriction variables selected for the summary matrix likewise apply here. Also, if the scenario fails to meet biomass demand targets for all years, only those in which targets are met will be shown.

Observations

Given the sheer number of combinations of supply variables, thresholds, and uncertainties viewable in the Biomass Tool, a single set of universal trends is difficult to convey. For these reasons, we recommend that users evaluate their own metrics of concern against the thresholds and uncertainties with which they are most comfortable. In the subsections below, we review a few such metrics and thresholds for the state of North Carolina to provide some context to the tool and its use, but shy away from making any single, universal conclusion about what the tool and underlying analysis can tell us about woody biomass use or its environmental or economic sustainability. This reluctance stems from the many factors that can influence the environmental or economic performance of any given scenario, the most important of which include variations in the size and composition of the forest and the amount and timing of the added demand.

The effect of these variations can be seen to some extent in Figure 3. Specifically, as we increase the amount of biomass demanded, we see that mature forest acreage in North Carolina falls relative to a baseline, without-biomass-demand scenario. In Georgia and South Carolina, the relationship is much more complex, with mature forest acreage either rising or falling at intermediate levels of demand. We also see the apparent existence of thresholds, beyond which dramatic changes in forest composition occur. For example, the dramatic drop in North Carolina mature forested acreage occurring between 10 and 15 million tons of total biomass demand is interesting for what it can tell us about the resource and the model application used. It represents a point on the ground where projected resource conditions have changed sufficiently to warrant a shift away from historical harvesting behavior. At this point, the model relaxes assumptions about where biomass may be sourced, here resulting in a significant and rapid drop in older planted pine stands as compared to the baseline scenario.

Figure 3. Change in mature forest acreage (age classes 9–11) relative to baseline conditions, plotted against maximum scenario biomass demand, for a) Georgia, b) North Carolina, and c) South Carolina.



Forested Acreage
Here, the metric of concern is the number of acres in age classes 9, 10, and 11, corresponding to a forest that is at least 40 years old. This is an important metric to observe when contemplating the effects of increased demand for woody biomass because of what it can tell us about management intensity. Given a large enough price signal, one could expect a general shift away from older, unmanaged, or less intensively managed forests towards younger, more intensively managed stands. While it would also be possible to evaluate the shift in management type over time (say for instance a shift from natural pine or upland hardwood to planted pine), an age class metric captures intensification across all management types as opposed to only the shift from a less intensive land use to a more intensive one.

Although the choice of the specific acreage threshold is up to the user of the tool, one potential threshold for purposes of demonstration could take a cue from acreage totals in established red cockaded woodpecker (RCW) conservation agreements. The Sandhills Safe Harbor Agreement, for example, has a permitted size of 500,000 acres (though actual landowner enrollment is likely significantly less).[9] The RCW requires mature forests and cavity trees for nesting, so a reduction in the acreage of older forests could conceivably negatively affect conservation objectives.

To gauge the incidence of increased demand for woody biomass reducing older forest acreage *statewide* by 500,000 acres, first select "North Carolina" as the state, "acreage" as the metric, units (acres of forest in age classes 9–11), a threshold of "500,000," a sensitivity of "25%," and a "2030" comparison point. The resulting summary matrix indicates those demand scenarios with the potential to experience a shift in older forests in year 2030 that fall within or exceed these values. The importance of timing in these scenarios is seen if one selects a "2025" comparison point instead. If using an "Annual Average" comparison point, a different summary matrix is provided, one that highlights the importance of the individual scenario comparison figures. Selecting a few scenarios for comparison, we see that some scenarios (100% RFS/10% RES, for example) exceed a hypothetical 500,000 acre threshold for one or more years, even though the 500,000 annual average is not exceeded in the summary matrix. A similar exercise may be conducted using percent as the metric.

Forest Carbon
Forest carbon is the total amount of carbon stored on forest lands in the study area, and includes carbon stored in live tree, dead tree, understory, down dead wood, and forest floor pools.[10] The total amount of carbon stored under a particular scenario is a function of both individual stand dynamics (e.g., management type, age class) and the total number of forested acres in a given year. Thus, total scenario carbon is closely linked to the forested acreage metric discussed above. This can be seen upon further examination of individual scenario carbon storage.

Influence of demand scenario on net forest carbon storage can be evaluated by again selecting North Carolina as the state, selecting the "carbon" radio button, units (metric tons C or percent), metric threshold, and metric sensitivity. In this case, it may be of some interest to evaluate the shift in stored carbon against the emissions associated with a large coal-fired electricity generation facility. Even within the state of North Carolina, emissions associated with such facilities vary widely.[11] Here, we choose a threshold of "2,500,000" metric tons carbon (approximately 9.2 million metric tons of CO_2e), an

[9] See: http://ecos.fws.gov/conserv_plans/servlet/gov.doi.hcp.servlets.PlanReport?plan_id=186&region=4&type=SHA&rtype=1, retrieved December 1, 2010.
[10] Estimates of carbon storage do not include carbon stored in harvest residues. This is to simplify carbon accounting. The carbon metric reported here is the amount of carbon on-site for any given year, and does not consider the future effects of residue decay or projected stand regrowth.
[11] See http://cfpub.epa.gov/egridweb/ for an overview of the CO_2 emissions associated with individual facilities (retrieved December 2, 2010).

uncertainty of "50%," and an "Annual Average" comparison point. The performance of the each scenario is indicated in the resulting summary matrix.

Selecting a few potential demand scenarios for individual comparison (for example, 50% RFS/1% RES), we see that in some cases, higher levels of biomass demand result in more carbon being stored across the landscape, not less. This largely occurs in those situations where there are large enough levels of biomass demand to create a price signal, resulting in an increased number of acres or an increasing intensity of forest management relative to the baseline, but in which increased harvest activity is modest enough to avoid significant depletion of existing carbon stocks. In situations where there are higher levels of demand (e.g., 100% RFS/10% RES), forest carbon stocks may be significantly lower than under baseline conditions.

It is important to emphasize that the metric displayed in the summary matrix reports forest carbon only; to determine the net GHG balance of the demand scenario, one must at the very least factor in the fossil emissions displaced by biomass use, as well as any leakage associated with displaced industrial capacity. Approximations of these components are both factored into the "Approximate GHG Balance" individual scenario comparison metric that appears below the matrix. When these are added to the observed change in forest carbon, we see that net GHG balance varies by both year and scenario, with negative values representing net emission reductions and positive values representing net increases. To gauge the potential effect of leakage from displaced pulpwood capacity, users may select "Yes" when prompted to include leakage immediately below the GHG balance figure. Users must then choose a leakage rate to apply to the GHG balance graph. For demonstration purposes, we can gauge the effect of 40% leakage, an approximation of the rate estimated by Murray et al. (2004) in their assessment of the market effects of large-scale afforestation projects.[12]

But again, net GHG balance metrics are included here simply for context. We caution users against drawing specific conclusions from the figures. The calculations on which they are based represent only a rough, first-order approximation of the potential effects of individual scenarios on GHG emissions. We have attempted to make this visually apparent by "fuzzing" and increasing the width of the figure lines themselves.

Potential Displacement

Potential displacement refers to the possible loss of pulpwood, pellet, or other industrial capacity in response to higher prices. In situations where the price of biomass increases, some existing users may essentially be priced out of the market. Those affected first will be the most price-sensitive, with the least ability to pass along higher costs to others in the supply chain or even directly to the end consumer. As in previous assessments, we assume that there is a mandate for meeting RES and RFS targets, and those faced with the compliance obligation (e.g., utilities, refineries) will have some mechanism to recapture their costs. Stated another way, we assume that the electricity- and fuel-producing sectors are not price-sensitive within the range of prices examined. Existing forest products industries, however, are bound by demand price elasticity of 0.5 (Abt and Ahn 2003), meaning that as biomass prices increase, they are the first to be priced out. This is an important assumption, and the primary reason why the metric is described as *potential* displacement; actual incidence of displacement will be dependent upon a great number of other factors, both including and in addition to assumed demand price elasticity.

With that caveat noted, potential displacement in North Carolina can be observed by first selecting the "potential displacement" radio button, selecting the units of the metric (either units in green tons of biomass or percent), metric threshold, and metric sensitivity. For example, a user may wish to see whether

[12] Note that this example value is included here simply for demonstration and convenience; the policy scenario modeled by Murray et al. is markedly different from the one considered here.

potential average annual displacement may exceed capacity of a particular mill or plant. Selecting "Units" for the metric, a threshold of "2,000,000" green tons, and an uncertainty of "50%" shows those demand scenarios in which potential displacement may exceed the size of a medium to large mill. As before, the comparison point plays an important part in the summary matrix output. Selecting "Annual Average" displays a different result than selecting "2030," for example. Note again, however, that these results represent *statewide* displacement potential, and do not refer to displacement experienced at any particular area within a state or by any particular facility. They likewise say little about the incremental displacement short of total plant or mill capacity that may make its operation unviable at some point.

Conclusions

Although the metrics covered and variables included herein are relatively simple, they provide the beginnings of a comprehensive overview of the range of impacts that increasing demand for forest biomass may have in a given state or region. We specifically note that the summary matrix in the associated Biomass Demand Interface Tool provides a useful overview of scenario trends, but the annual average on which it is based can mask important changes year-to-year. Therefore, it is important to make use of both the summary matrix and individual scenario comparisons when investigating the specific effect of a particular scenario on a particular metric. Combined, these two interface components provide the ability to simultaneously evaluate the effect of dozens of demand scenarios on multiple metrics of concern. Due to the multiple assumptions that are necessary to conduct such an analysis, we caution against taking the findings reported in the tool as an absolute indication of the specific impacts of a particular scenario. We further caution against interpreting any results as affecting a particular location or facility; all thresholds and effects refer to possible statewide effects only. Rather, the power of the tool is the ability to observe the high-level effects of multiple scenarios at the same time. We believe that such an approach has the potential to significantly increase our understanding of the trends and tradeoffs associated with increased use of forest biomass for energy and fuel production.

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