Estimating the Potential Supply of Biomass for Cofiring in Electricity Production in New York State

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Abstract

In order to effectively integrate renewable energy sources such as biomass into New York State's electricity market, industry leaders and policymakers must have access to accurate information about the potential supplies of biomass. Particularly, they require information on biomass resources that are currently available so that these resources may be used efficiently in the production of electricity through cofiring in existing coal-fired power plants. This technology has the potential to utilize renewable energy sources and reduce greenhouse gas emissions in the near future. This project seeks to estimate and map the supply of different sources of biomass through New York State in order to remedy the current lack of information available on this topic. Herbaceous energy crops, represented by switchgrass, and short-rotation woody crops, represented by willow, are considered as potential alternative feedstocks. Supplies are estimated based on land potential, land constraints, economic factors, and power plant capacities. GIS is used to map these factors. Varied scenarios are analyzed and discussed to illustrate a range of potential outcomes. The least intensive production scenario predicts a potential supply greater than the cumulative capacities of all power plants for cofiring. All other scenarios predict that production can meet capacity in more concentrated areas near power plants. This study finds that New York State has the resources to cofire biomass at all of its coal-fired power plants in the short-term.

1. Introduction

Concerns over energy independence and climate change are making policy decisions that affect the electricity sector increasingly relevant and important. New York State has already committed to a Renewable Portfolio Standard (RPS) and, along with other northeastern states, has signed the Regional Greenhouse Gas Initiative (RGGI). The RPS has set a goal for 25% of electricity consumption to come from renewable sources by 2013. RGGI is a regional agreement among the northeastern states to cap and trade CO_2 emissions in order to incrementally reduce emissions by 10% by 2018. These policies demonstrate the political and social desire to increase the use of clean, renewable energy.

Electricity producers, therefore, need to make quick adjustments to make these targets realistic. One option for utilities is to use biomass to produce electricity by cofiring it with coal in existing power plants. Biomass, essentially stored solar energy, can be a viable source of clean renewable electricity if its net energy contribution is positive. For the short-term, the most economical method of converting this energy into electricity is through cofiring (Hughes 2000). This method is especially attractive as a near-term solution because it can be implemented with existing technology and little investment. In fact, in 1991, biomass accounted for 2.4% of the total energy input into electricity generation in the US. The feedstock used most widely was wood, and roughly 70% of the wood was converted via cofiring (Easterly and Burnham 1996). Therefore, cofiring is an existing technology that can now be expanded to approach the goals of the RPS and RGGI.

Increased cofiring, however, will require significant increases in supplies of raw material. Typically, biomass has been made available for electricity production only as a waste of other product streams (Hughes 2000). Waste wood alone, if used for electricity generation, could produce 3-5% of the electric energy generated in the US (Hughes 2000). If dedicated energy crops are also produced and used to generate electricity, that figure can increase to 20% (Hughes 2000).

Careful land use planning and feedstock selection can help to maximize the potential of biomass resources, and thus make the developing industry as efficient as possible. Part of this process is deciding what feedstocks to use in cofiring. Biomass energy can come from several sources: short-rotation woody crops, herbaceous energy crops, agricultural residues, and forest residues. New York’s landscape is uniquely diversified, so there is ample opportunity to find various, low-cost supplies of biomass. Since so much land in the state is forest, management could easily be adapted to different levels of harvest for biomass in these regions. Agricultural land could provide residues from crops that are currently being grown, or could be converted to dedicated energy crops.

This study seeks to predict and analyze the developing market for biomass electricity feedstocks across New York State. As demand for these goods rises, landowners will realize the potential for profits in growing biomass for energy because the price at which they can sell will increase. At the point where their potential profits from biomass production exceed profits from food, forestry, or other existing land uses, landowners will begin to shift production. This study uses Geographic Information

Systems to spatially predict this shift in land use toward biomass production and how it will contribute to the state's renewable energy needs.

2. Related Literature

Researchers at Oak Ridge National Laboratory (ORNL) have implemented several studies using GIS to predict and analyze supplies of biomass feedstocks for energy. In 1993, the Erosion Productivity Impact Calculator (EPIC) was constructed to calculate the environmental effects and yields of crop growth in different areas based on inputs of soil, weather, crop type, and management practice data. Outputs from EPIC are used to identify suitable areas for the production of a specific crop like switchgrass within a specific radius from a power plant. Breakeven prices for the crop are also calculated for the crop and are used to determine supply from these suitable areas. Other studies from ORNL identify optimal locations for dedicated biomass power plants. (Graham and Downing 1993a, Graham and Downing 1993b, Graham 1994, Downing and Graham 1996, Noon and Daly 1996, Graham et al 2000).

Results indicate that switchgrass would be supplied at prices from \$35 to \$45 per dry ton, while SRWC feedstocks would be supplied at \$40 to \$50 per dry ton. Wood could solely support 18 GW of power and switchgrass could supply 30 GW in the Tennessee Valley Authority region (Downing and Graham 1996). Further, land use change in favor of biomass production is projected to result in environmental benefits, particularly in water quality (Graham and Downing 1993a). These predictions indicate promise for dedicated biomass energy crops in the future.

Other studies that use GIS to map feedstock potential make certain adjustments: evaluating the proposed site of a dedicated biomass electricity plant based on environmental, economic, and social factors (Varela et al 1999); optimal siting of power plants based on large-scale integration of short rotation woody crops into electricity production (Varela et al 2001); developing a decision support system for long-term analysis of the potential of agricultural and forestry residues for energy production (Voivontas et al 2001); and mapping potential supply of Eucalyptus based on predicted revenue and predicted costs of production (Bryan et al 2008). Although these studies each ask different questions, they all conclude that biomass has the potential to supply significant amounts of energy in the future and can do so while achieving numerous environmental and social benefits.

Tharaken et al (2005) estimates supply of willow within a 50 mile radius of existing pulverized coal electric plants for cofiring. Their analysis includes scenarios with combinations of three different incentive programs. They assumed that any land that could produce an internal rate of return of at least 15% would go into production of willow. IRR's increased with increasing incentives, and thus incentives were shown to increase the supply of willow to the power plant.

While these papers do contribute useful knowledge and methodologies to the literature, they fall short in many areas. First, the incorporation of multiple feedstocks into the predicted supply and analysis is rare. Second, those papers that do use spatial assessment of possible supplies neglect comprehensive economic analysis. Third, studies typically focus on long-term potential supplies, which is not useful for short-term planning. This honors thesis will help to overcome these shortcomings by providing an accurate, detailed projection of biomass supply for electricity for the near future in New York State.

3. Methodology

A. Data

Most data were compiled and analyzed using ArcGIS 9.3 (Environmental Systems Research Institute) and Microsoft Excel (Microsoft Office 2003). Land potential was analyzed based on land use data. Here, the 2002 Cropland Data Layer (USDA 2002) was used. Geographic constraints were incorporated from data on state and federal lands and high-sloping lands. State lands were mapped from a shapefile of Department of Environmental Conservation (DEC) Lands for New York (NYSDEC 2008). Federal lands were obtained from the Atlas of Federal Lands map (National Atlas 2005). Slopes were mapped by transforming 7.5-minute Digital Elevation Model rasters (USGS 1999) to maps of percent slope. Additionally, wetland or urban classification was assumed to be a constraint, and was therefore also taken from the 2002 Cropland Data Layer (USDA 2002).

Price and yield projections for willow and switchgrass were extracted from published literature. For conventional crops, prices and yields were averaged from the National Agricultural Statistics Service's data and statistics for 2007 and 2008 (USDA-NASS 2007, USDA-NASS 2008).

For spatial aggregation, the Zip Code Tabulation Area (U.S. Department of Commerce 2007) shapefile for NY was used. Zip code boundaries were used to tally land areas, constraints, and finally supplies within a given area.

Coal-fired power plant locations and data were taken from the eGRID2006 Version 2.1 database (Environmental Protection Agency 2007). A road network for New York was constructed from the NYS Streets vector file (NYS Office of Cyber Security

2009) using the Network Analyst Toolbar in ArcGIS. These data were used to incorporate transportation costs from each zip code to power plants.

B. Conceptual Framework

This study calculated potential supply based on landowner and power plant perspectives. First, the landowner's decision to produce biomass instead of continuing the existing land use was modeled. Next, the power plant's decision of from where biomass ought to be purchased was modeled. The following sequence was used:

Landowners:

I. Associate current land use with potential production of biomass crops

II. Model decisions to produce biomass for electricity

III. Map factors that prevent production

IV. Calculate total areas of potential supply

Power Plants:

V. Relate potential supply to existing power plants' capacities and locations

I. First I determined on what type of land each biomass feedstock is most likely to be grown. Short-rotation woody crops, for which willow was used as a representative example, were assumed to be grown on some timberland. Forest owners that have harvested before are more accustomed to harvesting woody species on several-year rotations and may have some of the necessary equipment, which would reduce their start-up capital costs. Land in the Conservation Reserve Program was also assumed to enter willow production, because landowners can still receive partial CRP payments and profit from the sale of willow. This hybrid method of combining harvest and conservation has been shown to reduce feedstock production costs and government spending on CRP payments (Tharakan et al 2005). Herbaceous energy crops, however, are harvested much more like typical agricultural crops, so owners of farmland are more likely to grow a biomass crop like switchgrass. Land currently in pasture, however, was not included as a likely source for energy crops because dairy farmers already have large investments in their industry and would need new equipment to harvest energy crops. These factors make pastureland less likely to be used for biomass production in the short-term. Switchgrass was used as the representative crop of this category. The 2002 Cropland Data Layer (USDA 2002) was used to identify areas of agriculture and forest that could potentially shift toward switchgrass or willow production, respectively.

II. Next, I determined the areas in which switchgrass production could lead to higher revenues for landowners than the current crop. Revenues were used in lieu of profits because of a lack of current data on the costs of production of both conventional crops and biomass crops other than willow in New York. Per hectare revenues were calculated by multiplying projected prices for the appropriate crop by their projected yields. Where revenue from switchgrass production exceeded revenue from conventional row crops by 15%, the landowner was assumed to shift toward biomass production. While this method is not as precise as comparing profits, it serves as an indicator for potential profitability when costs of production are not known for each option. These calculations were done for several different price scenarios: $1.50, $2.00, $2.50, and $3.00 per GJ. These prices are adapted from Downing and Graham (1996), Walsh et al (2003), and Tharakan et al (2005). Switchgrass yields were projected to be 9.8 dry tons per hectare based on field trials in Iowa (Duffy and Nanhou 2002). This value has been shown to be similar to yields in the northeast (Timmons et al 2008). The low and high yield scenarios used were 2.75 dry tons per hectare and 15 dry tons per hectare (adjusted from Perrin et al 2008, Duffy and Nanhou 2002). The high heating value used for switchgrass was 16.0 GJ/dry ton (Mani et al 2004).

However, owners of forested land typically do not harvest forest products or shift land use even if they can earn more money. Only 35% of landowners in New York stated they would harvest from their forests between 1995 and 2005 (Birch 1995). These forests make up 54% of the state's private forestland (Birch 1995). Most owners of forestland prefer to leave the forest untouched for environmental, recreational, or other typically nonmonetary benefits (Birch 1996), so a revenue comparison would be misleading. Further, it is unlikely that all landowners who stated willingness to harvest from their forests would be willing to shift entirely to willow production for biomass. Therefore, predicting how much and which forestland in the state will be converted to biomass production using economic indicators is difficult. Therefore, I analyzed different rates of forest conversion to account for this uncertainty. The highest level of private forest conversion allowed was 54%, but values of 5% and 20% conversion were also used to estimate supply under more realistic conversion scenarios. Willingness to shift to biomass production was assumed to be homogenous throughout the state.

Per hectare revenues were calculated for willow by multiplying the projected prices per GJ by yields of 6, 11.5, and 20 dry tons per hectare per year (adjusted from Tharakan et al 2005, Timmons et al 2008) and a high heating value of 16.6 GJ per dry ton (Tharakan et al 2005). Rather than comparing these revenues to those earned on conventional forestland, these values are calculated simply for comparison to switchgrass.

III. Subsequently, conditions that prevent production of biomass were mapped. These include state and federal lands protected from harvest, urban areas, wetlands, and high-sloping lands. Biomass was assumed to be harvested on slopes up to 6% in the normal scenario (Pierce et al 1983, Varela et al 2001). However, willow can have benefits on water quality and erosion if planted on more extreme slopes (Kort et al 1998). Therefore, I also considered harvest of willow on slopes up to 8%, at which point harvest becomes unsafe (Castellano et al 2009). Any of these constraints would prevent a landowner from producing biomass, even if factors from the previous steps are favorable.

IV. Next, total areas and quantities of supply of each type of biomass feedstock were calculated. Rather than using a grid layout to predict supply of each good in each cell, I analyzed supply at the zip code level, which is more applicable for policy and utility planning. Areas of DEC and federal lands were calculated for each zip code in ArcMap using the Intersect tool in the Analysis Toolbar, followed by the Dissolve tool in the Data Management toolbar, and finally by adding an area field to the resulting attribute table. Areas for the cropland and slope rasters were calculated for each zip code using the Tabulate Area tool of the Spatial Analyst toolbar.

The areas of all the cropland for which revenues of switchgrass exceed those of the conventional crops by 15% are totaled for each zip code under each price and yield scenario. For willow, the different rates of conversion are multiplied by the area of forestland in each zip code to give the areas of potential willow production. Additionally, the acreage of CRP and idle cropland in each zip code was added to the acreage for willow from converted forest. These acreages were then adjusted for land that is ineligible for any type of harvest. For each zip code, the proportion of area that is ineligible for production is multiplied by the total area of projected supply for that zip code to approximate ineligible land area. This area is subtracted from the initial supply estimate to give approximate area of eligible supply of each feedstock in each zip code.

V. However, not all of this potential supply will enter production of biomass. Power plants can only cofire biomass feedstocks at proportions less than or equal to 10% of the total energy input, before suffering significant efficiency losses (Hughes 2000). Therefore, there is a limit on how much biomass can be cofired at each plant. To determine what biomass is most likely to enter production of electricity, relative transportation costs were calculated. Power plant operators are more likely to buy feedstocks with low transportation costs. Relative transportation costs of biomass to the nearest coal-fired power plant were generated in an Origin-Destination Cost Matrix using the Network Analyst, which calculates the road distance from point to point. Since distance is proportional to travel cost, those sources that are nearest to a power plant are assumed to have the lowest transportation cost. Therefore, power plants will select these sources to apply to their 10% input capacity.

This methodology is most appropriate for the state in the short term given the interests of policymakers and utilities, as well as the availability of spatial data for New York. Other studies typically only map the production of one type of feedstock; however, power plants are able to cofire multiple types of biomass if the profits are high enough. Therefore, it is best to consider what types of biomass can maximize production of energy in a given area, and thus maximize profits for biomass producers. Furthermore, policymakers require a complete picture of the renewable energy production industry to design effective policy. Predicted supplies of one type of feedstock, or supplies from only one specified area are insufficient to understand the statewide market for renewable energy sources.

C. Analytical Framework

The landowner's decision to produce biomass in favor of continuing his or her current land use is modeled by the following functions:

$$D_S = f(P, a),$$

for switchgrass, where P is the potential for increased profits from biomass and a is the ability to produce biomass in a given area, and:

$$D_W = \beta * f(a),$$

for biomass, where β is the proportion of private forestland that is likely to undergo conversion. Potential for increased profits is modeled by

$$P = (Y_S * p_S) - 1.15(Y_C * p_C),$$

where Y and p represent the yield and price of switchgrass, S, and conventional crops, C. Ability to produce biomass is determined according to the following function:

$$a = f(L, c),$$

where L is the land use and c is the presence of any constraints.

Power plant utilities decisions to buy biomass are modeled for this analysis in the following form:

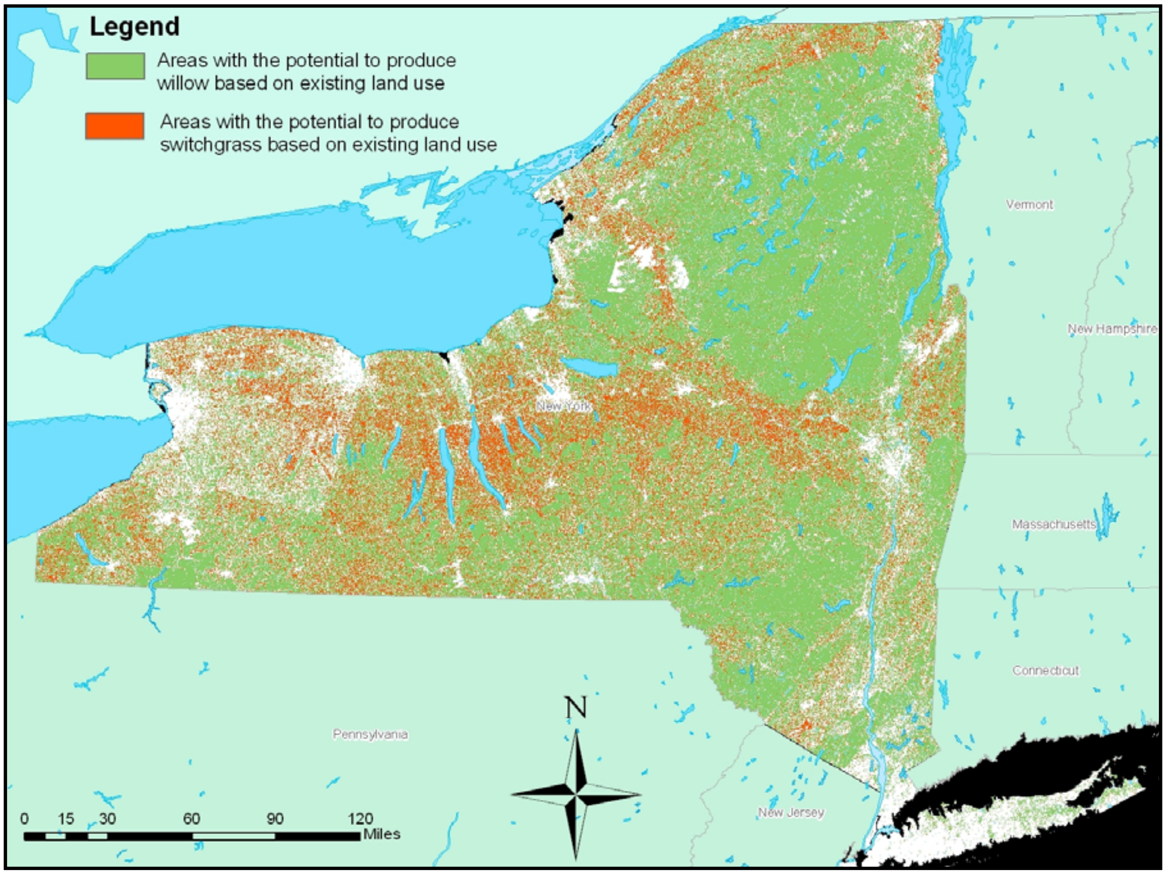
$$D_U = f(TC, \alpha),$$

where TC is the transportation cost of biomass to the power plant and α is the amount of biomass that can still be cofired before reaching capacity. Transportation costs are proportional to the distance from the power plant to the biomass source.

4. Results

I. Figure 1 indicates the initial potential areas for switchgrass and willow production. There are very large areas of forest, particularly in the Adirondack and Catskill regions, that could be used for willow, based on their current land use. Switchgrass potential is concentrated more in the central region of New York extending nearly from Albany to Buffalo.

Figure 1. Map of Potential Areas for Willow and Switchgrass Production Based on Land Use Only



II. Switchgrass will only compete for conventional cropland if it obtains high yields and prices of at least $2.50 per GJ. In these cases, per hectare revenues would exceed those of oats, barley, and non-alfalfa hay by at least 15%. Further, no more land is outcompeted when the price increases from $2.50 to $3.00 per GJ. In the scenarios with lower prices and/or yields, revenues failed to exceed those of any common conventional crops.

Table 1. Per Hectare Switchgrass Revenues ($)

	Low Yield	Middle Yield	High Yield
$1.50/GJ	66	235.2	360
$2.00/GJ	88	313.6	480
$2.50/GJ	110	392	600
$3.00/GJ	132	470.4	720

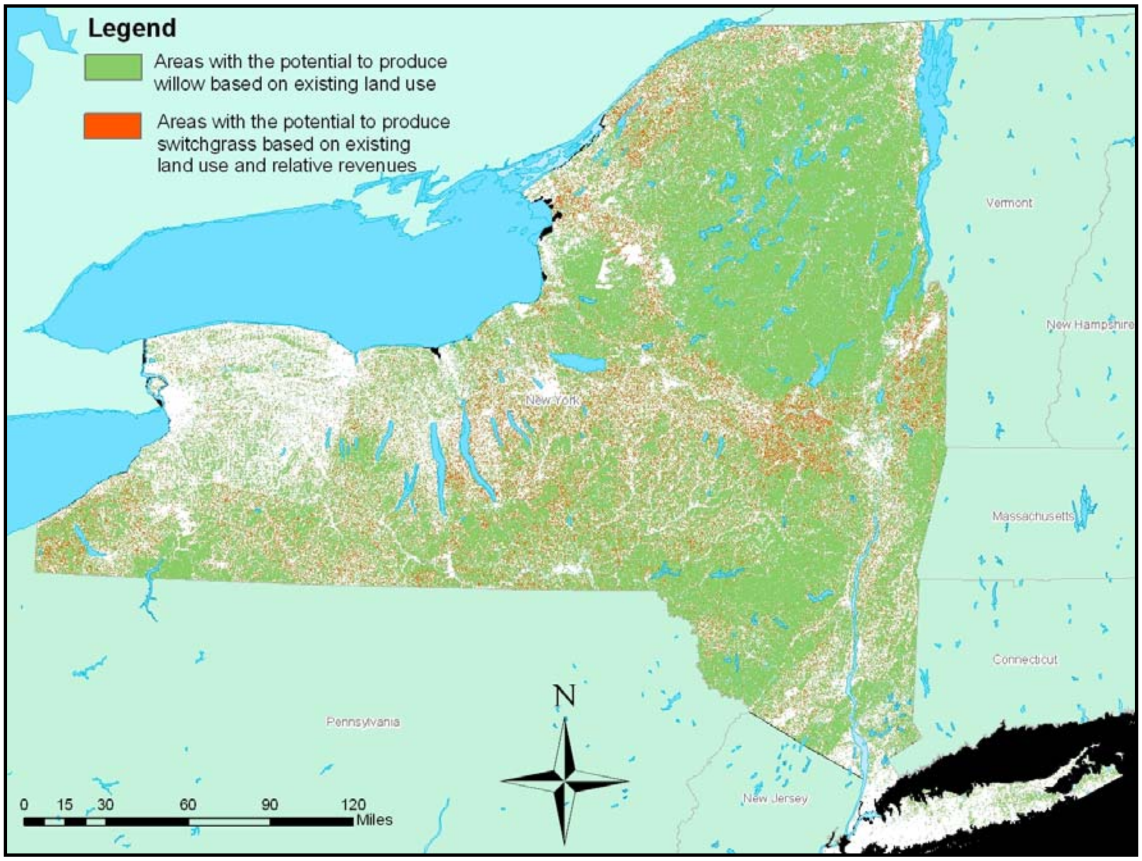
Projected willow revenues are higher than those of switchgrass. High yields would still need to be achieved for willow to compete with conventional crops. However, under the high yield scenario, willow would begin competing at prices of $2.00 per GJ, rather than prices of $2.50 per GJ for switchgrass.

Table 2. Per Hectare Willow Revenues ($)

	Low Yield	Middle Yield	High Yield
$1.50/GJ	149.4	286.35	498
$2.00/GJ	199.2	381.8	664
$2.50/GJ	249	477.25	830
$3.00/GJ	298.8	572.7	996

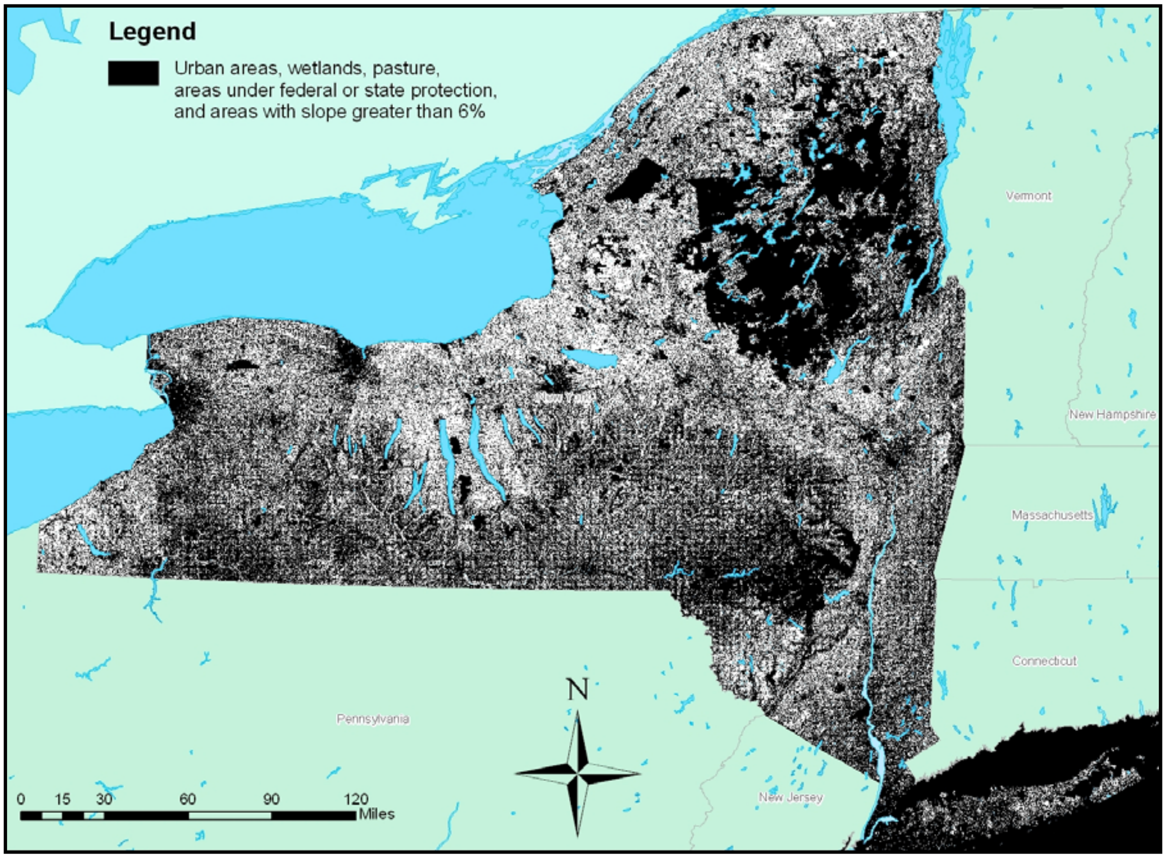
When compared to Figure 1, Figure 2 demonstrates the dramatic decrease in the area of potential switchgrass production when relative revenues are factored in. Willow is unchanged from Figure 2 because revenues are not a main factor in determining supply, which comes primarily from forestland.

Figure 2. Map of Potential Economically Viable Willow
and Switchgrass Sources



III. Figure 3 indicates all areas in which production of biomass is unlikely. The map shows vast areas in the Adirondack region that cannot be used for production because they are protected by the state. There are also significant areas of pasture land, particularly in the western region of New York, where neither switchgrass nor willow are likely to compete for land. The Southern Tier and Catskill regions are dominated by highly sloping land, on which harvest of any type of crop is unfeasible and unsafe. Lastly, there are significant urban areas on Long Island and around Syracuse, Rochester, and Buffalo.

Figure 3. Map of Geographical Constraints on Production of Biomass



IV. Because switchgrass only competed with conventional agriculture at high yields and prices, potential areas for production were totaled for only two scenarios: harvest on slopes up to 6% and harvest on slopes up to 8%. Areas did not vary between $2.00 and $2.50 per GJ because no additional land uses are outcompeted at the higher price. At slopes up to 6%, over 10 million dry tons of switchgrass could be produced on about 2600 square miles of land. This amount could be used as feedstock to generate over 160 million GJ of electricity. At slopes up to 8%, over 11 million dry tons could be produced on about 2900 square miles, which could produce nearly 180 million GJ. When yields are at low or medium levels, or the price is less than $2.50 per GJ, no area is devoted to switchgrass production.

The potential areas and quantities of willow were totaled for different rates of private forest conversion, the two slope scenarios, and varying yields. On slopes up to 6%, the area of land converted to willow was about 1200 square miles, 3900 square miles and 10000 square miles, for 5, 20, and 54% conversion of private forestland, respectively. At low yields (6 dry tons per ha), these areas translate to 30 million, 100 million, and 260 million GJ. Medium yields (11.5 dry tons per ha) could produce 60 million, 190 million, and nearly 500 million GJ. High yields (15 dry tons per ha) could produce 100 million, 335 million, and 860 million GJ. When the slope limit is increased to 8%, areas increase to about 1300, 4300, and 11000 square miles. At low yields (6 dry tons per ha), these areas translate to 34 million, 110 million, and 290 million GJ. Medium yields (11.5 dry tons per ha) could produce 65 million, 215 million, and 550 million GJ. High yields (15 dry tons per ha) could produce 115 million, 370 million, and 950 million GJ.

In total, depending on the yields, slope limits, and rates of forest conversion, the total area undergoing land use change to produce biomass for electricity for cofiring can range from 1200 square miles to nearly 14000 square miles. Total energy production could therefore range from 30 million GJ to over 1 billion GJ.

V. There are 15 power plants in New York for which the main fuel supply is coal. If each of these plants were to substitute 10% of their annual heat input in coal for biomass, they could accept a total of approximately 26 million GJ from biomass, which is less than even the potential supply of biomass in least-intensive scenario. The average distance from a zip code to the nearest power plant was 50 miles. The minimum and maximum distances were 0.82 and 159 miles, respectively.

In the least intensive scenario where switchgrass is not produced at all and 5% of private forest can be converted to willow at a yield of 6 dry tons per ha at slopes up to 6%, the entire 26 million GJ capacity of biomass can still be supplied. However, it would be supplied much less efficiently than in more intensive scenarios. Zip codes supplying to their nearest power plants could supply nearly 10 million GJ of willow biomass. In this case, 808 zip codes, out of 1675 zip codes in the state, would supply to their nearest plant. The average distance for these areas to ship biomass to the nearest plant is 32 miles. The remaining 16 million GJ would have to come from zip codes that are actually closer to another plant, but to which they cannot supply because the plant would have reached capacity from other, closer zip codes.

In a low to moderately intensive scenario with harvest occurring on slopes up to 6%, forest conversion at 5%, willow yield of 11.5 dry tons per ha and switchgrass yield of 15 dry tons per ha, the entire capacity of biomass for cofiring could be supplied more efficiently. By supplying only to their nearest power plants, zip codes could supply nearly 21 million GJ from biomass. All of this biomass would come from 429 zip codes. The average distance from these zip codes to their nearest plants is 26 miles. The remaining 5 million GJ of biomass would have to come from areas supplying to plants that are further away.

In a moderate to highly intensive scenario with harvest occurring on slopes up to 8%, forest conversion at 20%, willow yield of 11.5 dry tons per ha, and switchgrass production occurring (price of at least \$2.50/GJ and high yield of 15 dry tons per ha), capacity is reached even more easily. Supplying to their nearest power plants, zip codes could supply 22 million GJ from biomass. This biomass would come from 207 zip codes.

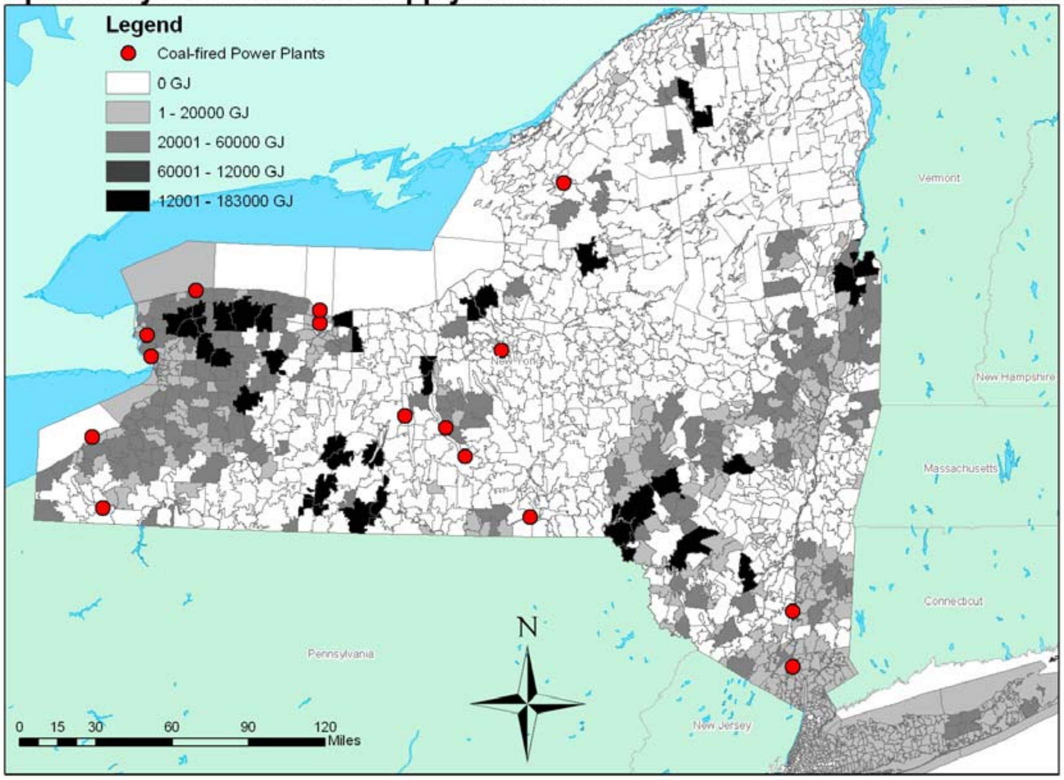
The average distance needed to travel to the nearest plant would be 16.8 miles. The remaining 4 million GJ needed to reach capacity would have to come from zip codes supplying to more distant plants.

In the most intensive scenario, in which harvest can occur on slopes up to 8%, 54% of private forestland can be converted to willow at a yield of 20 dry tons per ha, and switchgrass is produced (price of at least $2.50/GJ and high yield of 15 dry tons per ha), the capacity supply is reached from very few zip codes. In this scenario, 25.6 million GJ of biomass would be delivered from zip codes to their nearest power plants. Only 68 zip codes would supply biomass, at an average distance of 15 miles. The small portion of remaining biomass would come from zip codes for which their nearest plant has already reached capacity.

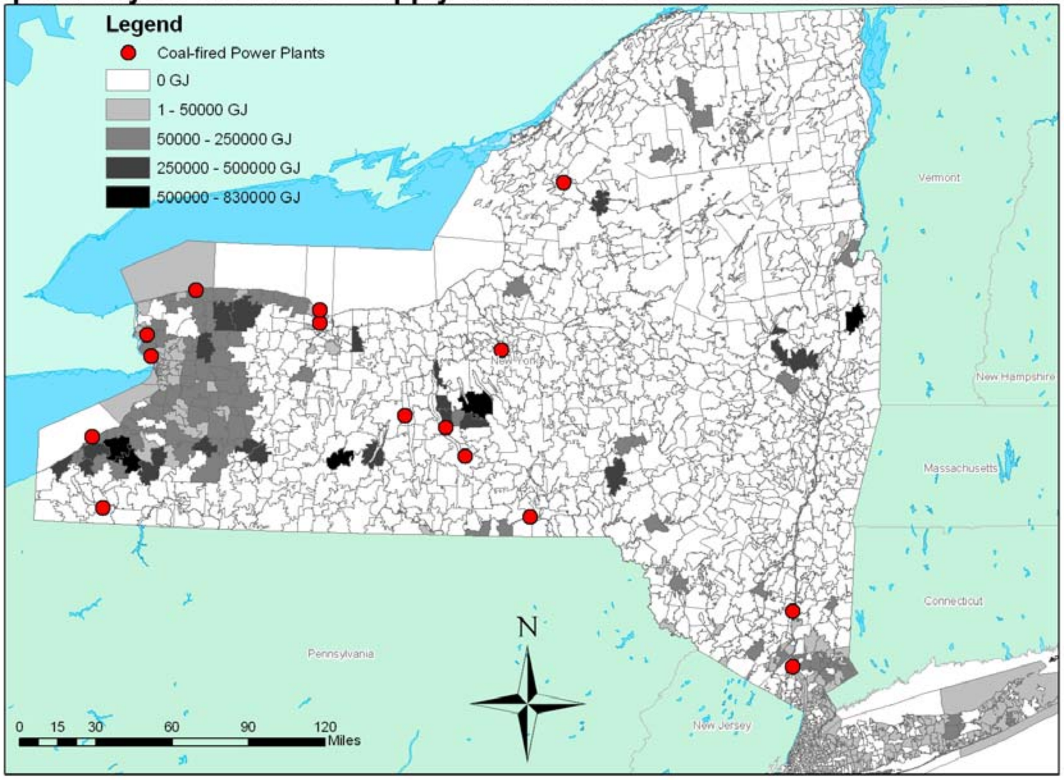
Table 3 summarizes these results. In each scenario, more than enough biomass is produced to reach the cumulative capacity of the power plants for cofiring. Increasing the slope limit, prices, yields, and/or private forest conversion, however, increases the efficiency of the supply. Higher proportions of the biomass can be sold to power plants that are nearest to a zip code, rather than to plants that are farther away, reducing the average transportation distance. Furthermore, the biomass needed can come from fewer zip codes overall as the production becomes concentrated in smaller areas near plants.

The maps on the following two pages illustrate the spatial supply of biomass under each of these four scenarios. Each map depicts the amount of biomass the zip codes are able to supply to their respective nearest coal-fired power plants, which are also displayed on the maps.

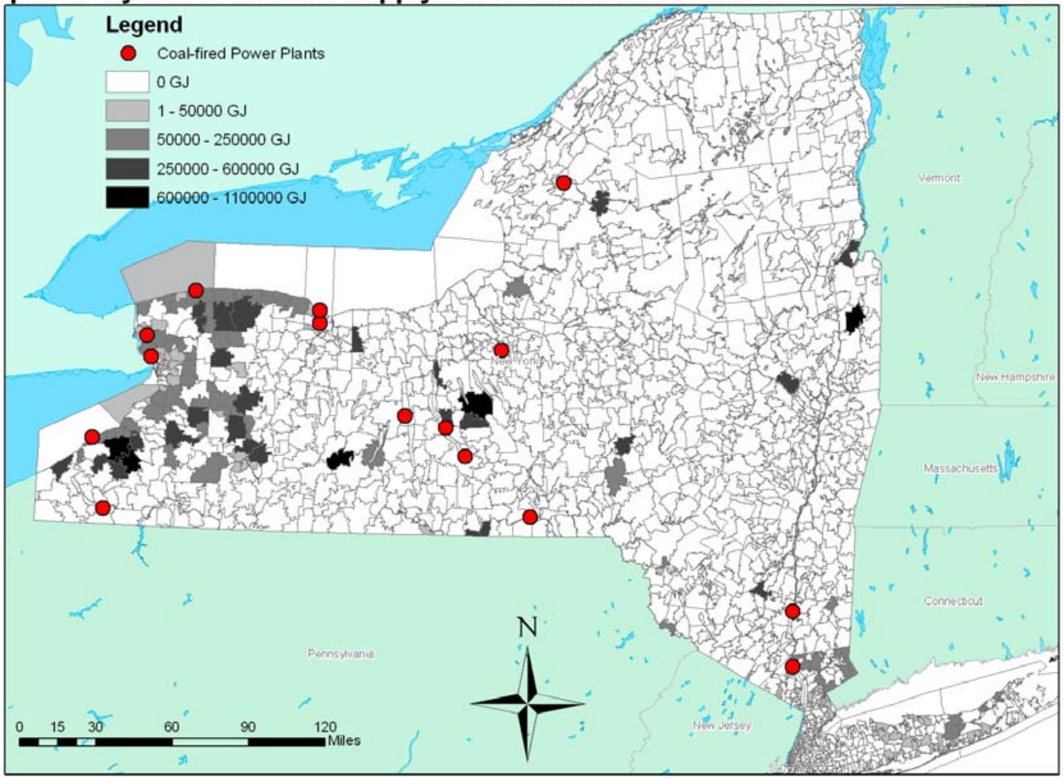
Spatial Layout of Biomass Supply under Least Intensive Conversion Scenario



Spatial Layout of Biomass Supply under Low-to-Moderate Conversion Scenario



Spatial Layout of Biomass Supply under Moderate-to-Intense Conversion Scenario



Spatial Layout of Biomass Supply under Most Intense Conversion Scenario

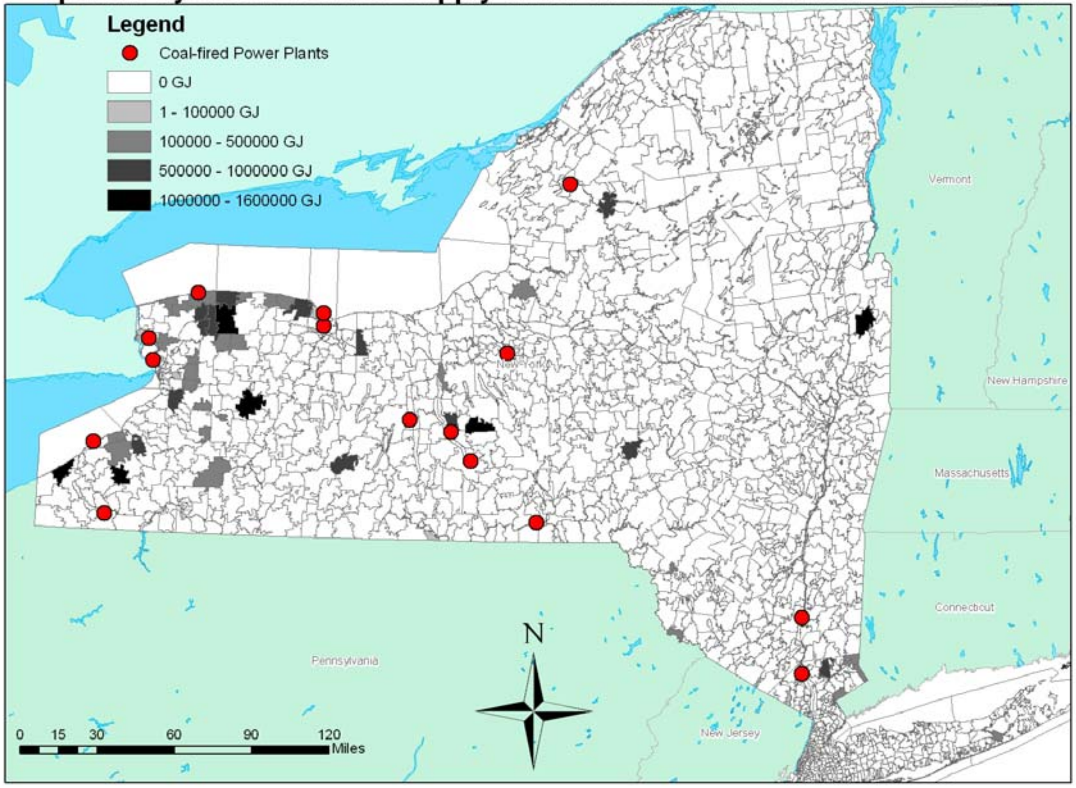


Table 3. Results of Predicted Supplies under Difference Scenarios of Conversion to Biomass Production

Scenario	**Least Intensive**	**Low-to-Moderately Intensive**	**Moderate-to-Highly Intensive**	**Most Intensive**
Slope Limit	6%	6%	8%	8%
Price	< $2.00 / GJ	$2.50 - $3.00 / GJ	$2.50 - $3.00 / GJ	$2.50 - $3.00 / GJ
Switchgrass Yield	< 15 dt/ha	15 dt/ha	15 dt/ha	15 dt/ha
Willow Yield	6 dt/ha	11.5 dt/ha	11.5 dt/ha	20 dt/ha
Private Forest Conversion Limit	5%	5%	20%	54%
Supply				
Biomass Energy supplied to Nearest Plants	9,867,574 GJ	20,810,329 GJ	21,650,167 GJ	25,650,167 GJ
Efficiency Indicators				
Number of Zip Codes supplying to Nearest Plant	808	429	207	68
Average Distance to Nearest Plant	32.0 mi	26.5 mi	16.8	15.0 mi

5. Discussion

Results from this preliminary analysis of the potential biomass supply in New York state indicate promise to support cofiring of biomass at all of the state’s coal-fired power plants. Each scenario analyzed predicted a supply high enough to reach the cumulative capacity of the power plants to cofire biomass with coal at a rate up to 10% of total heat input. Scenarios for which conversion to biomass production was modest, however, are less efficient because the distance required to transport the biomass to power plants was high. When land use conversion is more aggressive, the production of biomass is much more concentrated near power plants, which reduces transportation costs.

In 2007, all electricity generated in New York State totaled about 525 million GJ (EIA 2009). If all coal-fired power plants cofire biomass at levels of 10% heat input and consume 26 million GJ of biomass energy in the process, they could displace approximately 6% of the energy generated from fossil fuels like coal and natural gas. The goal of NYS's Renewable Portfolio Standard is to increase the share of the state's renewable energy from the 2004 baseline of 19.3% to 25% by 2013. Cofiring biomass, therefore, has the potential to help the state approach this goal very easily. However, it would be unrealistic to try to reach the goal through cofiring alone, since some power plants already cofire at low levels, so some of the 6% potential is already being realized.

Further, the goal of RGGI is to reduce greenhouse gas emissions from the northeastern states by a total of 10% by 2018 by implementing a cap and trade system for CO_2 emissions by power plants. Displacing 6% of fossil fuel feedstocks for electricity with a clean, renewable fuel like biomass can theoretically reduce net greenhouse gas emissions. The growth of the biomass involves uptake of greenhouse gases, so only those gases that were captured during growth are released during cofiring. Therefore, the entire 6% fossil fuel displacement would lead to an equivalent net reduction in emissions from the power plant. However, other additional emissions are likely to result from the growth, harvest, and transportation of biomass, so the effective net reduction in greenhouse gases by substituting biomass is limited.

Nonetheless, under RGGI, power plants that implement cofiring have the ability to bring in extra revenues. Power plants that reduce their carbon emissions are able to sell carbon emission permits. One method of emission reduction is substitution of fossil fuel feedstocks in favor of biomass. Therefore, those plants that cofire can then sell carbon permits for the equivalent amount of emission reduction. These potential extra revenues are not considered in this study, but could have very important effects in how a biomass market develops in the coming years.

While this study indicates a promise for the potential of biomass to be supplied for cofiring, there are important considerations to recognize in the data and methods. First, the analysis is based largely on existing land use data, which is derived from satellite imagery. This type of data has inherent uncertainty, which limits the level of certainty one can have in very specific spatial projections based on the data. This problem reflects the need for and the potential utility of collecting accurate, spatially explicit, and high resolution data about land use, management, ownership, etc.

Next, this study was conducted with limited economic data. To best predict where alternative crops like switchgrass and willow will compete, a comprehensive economic model is needed. Further, a model that considers the typical forestland-owner's behavior explicitly is especially valuable in this case. This method would allow for accurate modeling of the landowners' decisions under predicted changes in the prices and yields of both existing and alternative crops. This study, however, uses predicted revenues as an indicator of potential profitability of switchgrass because cost-of-production data for each crop type was not found.

For willow, which is predicted to be grown mostly on forestland, several scenarios of forest conversion are analyzed to reflect the range of possible outcomes for a future supply of willow. Past studies (Tharakan et al 2005) have typically looked at willow as an economic competitor with existing land use. They conclude that willow can only be economically viable for power generation if incentives are implemented in policy. However, most forestland owners are not concerned with the profits they gain from forest; they maintain forests on their land for aesthetic, recreational, environmental or other nonmonetary reasons. Some portion of landowners may be willing to shift some forest to willow production, because it can provide environmental benefits similar to those of a forest. Another portion of landowners may switch only if they can achieve higher profits. Therefore, this study evaluated supply at different levels of forest conversion to account for the potential range of outcomes. More careful study is necessary to really understand how different types of landowners will change their behaviors when confronted with growing markets for biomass for energy.

Further, because willow was shown to produce higher revenues than switchgrass, it is possible willow is actually more likely to compete with conventional crops than switchgrass, unless costs of production of the latter are much lower. However, many farmers of conventional crops would need to adjust more drastically for willow than they would for switchgrass. If willow were a better competitor for agricultural land in New York, the supplies would need to be adjusted based on production solely of willow, rather than both willow and switchgrass. These factors also ought to be studied more thoroughly.

Lastly, it is important to recognize that there are other potential sources of biomass from which power plants can obtain feedstock. Even if land use conversion does not occur, or occurs only on a limited scale, there is potential to harvest residues from existing crops or forest. Residues may be a financially cheaper option for power plants than dedicated energy crops, but the removal of residues can have lasting negative environmental and economic impacts. Additionally, solid waste from industry and municipalities has the potential to be cofired with coal as biomass. These sources could also be cheap since there is little demand for them, and their use as a feedstock would prevent their waste, to some extent. A recent study that closely investigated the potential for supply of both residues and dedicated energy crops was conducted by Castellano et al (2009). However, they only considered several types of woody biomass residue along with willow, and do not consider herbaceous energy crops. Further, this study took place on a small-scale, so its application for statewide planning is limited. A comprehensive, spatial study that takes into account the potential supplies of all of these types of biomass feedstocks throughout the state, region, or country will be most useful for advising utility planners and policymakers.

Concurrent to the execution of this study, New York State funded an overarching renewable fuels and sustainable biomass feedstock supply evaluation, which, at the time of submission of this paper, is in the draft phase. This “Renewable Fuels Roadmap” involved predicting the spatial supply of available feedstocks for energy production, similar to this thesis. According to the draft, part of the vision for New York State is to have a “vibrant, world-class biofuels industry” that uses diverse feedstocks in the most sustainable manner possible, cost-effectively reduces greenhouse gas emissions and petroleum imports. The report analyzes the potential for the development of this type of industry, evaluates consequences, and makes policy recommendations. In the large scale of the study, the authors involved many important factors that were left out in this paper, including: quantification of economic and environmental impacts, consideration of waterway and rail transportation, consideration of competing markets for biomass goods (biorefineries, coal-fired power plants, pulp and paper plants, pellet plants, sawmills, and firewood producers), consideration of demand from adjacent states and Canada, a life cycle assessment of biomass fuels, and a thorough discussion of policy and recommendations. (Wojnar et al 2009)

Nonetheless, the Renewable Fuels Roadmap fails to provide a complete understanding in many important ways. First, the time-scale for most of the analysis is 2020 to 2030. Thus, there is no analysis of the immediate potential for biomass use in energy production. Accordingly, all the supply projections are for consumption by biorefineries, which are still questionable in terms of their efficacy for energy production and greenhouse gas emission reductions. These biorefineries produce liquid fuels from biomass, and thus would be used for transportation fuels, but would not do anything for electricity production. Despite a small consideration of coal-fired power plants as a competitor for biomass, this approach leaves electric utilities with little information on how best to utilize the renewable resources of the state.

Even when these “big picture” flaws are ignored, some of the methods of the Roadmap study are faulty. First, and most importantly, not one of the projected supply scenarios considers competition for land use. The authors only consider the potential for dedicated biomass crops to be grown on non-forested land and land made available after yields of crop and milk increase. Theoretically, if crop and milk yields continue to increase, the amount of land needed to maintain supply of these goods will decrease, and more land will be made available for biomass production. While this factor may be an important variable in how lands are allocated to biomass production, it ignores the potential for biomass to economically compete with agriculture and to be grown on forestland for its environmental benefits. Even though this thesis only uses a revenue comparison as an indicator for potential profitability on agricultural land, it comes a lot closer to providing a realistic supply scenario based on current land use.

The best method for the state and industry to evaluate renewable energy potential will involve combining the short-term supply options from this thesis with the long-term options considered in the Renewable Fuels Roadmap. Methodologies for modeling landowners' decisions need to be improved, but must account for economic competition in land use and production solely for environmental, aesthetic, and other nonmonetary reasons. The more spatially explicit a supply projection can be made, the more useful it will be. Further, supply estimates must consider all available feedstocks and competing uses.

6. Conclusion

Despite the limitations and uncertainties in this study, it unambiguously indicates that there is significant potential to produce biomass to cofire for electricity generation in New York State. Further, cofiring biomass can have a very major impact on the state's approach toward meeting targets set in the RPS and RGGI. Most importantly, cofiring can have nearly immediate environmental and economic benefits, given its existing technical feasibility. Nonetheless, for the benefits of cofiring to be realized, land use change and market shifts must begin soon. Landowners, particularly farmers and forest owners, ought to be informed of biomass's potential for electricity production and of policies like the RPS and RGGI. That information will surely initiate evaluation of their potential options for biomass production. Upon distribution of this information, it will be much more likely that New York State will realize higher renewable energy shares at relatively low cost in the near future.

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References

Birch, T.W. 1995. Forest land parcelization and fragmentation. USDA Forest Service, Northeastern Forest Experiment Station. Radnor, PA.

Birch, T.W. 1996. Private forestland owners in the United States, 1994. Resource Bulletin NE-134, USDA Forest Service, Northeastern Forest Experiment Station. Radnor, PA.

Bryan, B.A., Ward, J. and Hobbs, T. 2008. An assessment of the economic and environmental potential of biomass production in an agricultural region. Land Use Policy 25(2008): 533-549.

Castellano, P.J., Volk, T.A., and Herrington, L.P. 2009. Estimates of technically available woody biomass feedstock from natural forests and willow biomass crops for two locations in New York State. Biomass and Bioenergy 33: 393-406.

Downing, M. and Graham, R.L. 1996. The potential supply and cost of biomass from energy crops in the Tennessee Valley Authority Region. Biomass and Bioenergy 11(4): 283-303.

Duffy, M. D. and Nanhou, V.Y. 2002. Cost of Producing Switchgrass for Biomass in Southern Iowa. Trends in new crops and new uses. J. Janick and A. Whipkey. Alexandria, VA, ASHS Press.

Easterly, J.L., and Burnham, M. 1996. Overview of biomass and waste fuel resources for power production. Biomass and Bioenergy 10(2-3): 79-92.

Energy Information Administration (EIA). 2009. New York Electricity Profile. Retrieved 25 Oct. 2009, from <http://www.eia.doe.gov/cneaf/electricity/st_profiles/new_york.html>.

Graham, R.L. 1994. An analysis of the potential land base for energy crops in the conterminous United States. Biomass and Bioenergy 6(3): 175-189.

Graham, R.L. and Downing, M. 1993. Renewable biomass energy: Understanding regional scale environmental impacts. Biomass Conference of the Americas: energy, environment, agriculture, and industry. Burlington, VT. 30 Aug – 2 Sep 1993.

Graham, R.L. and Downing, M. 1993. Evaluating a biomass resource: The TVA region-wide biomass resource assessment model. Biomass Conference of the Americas: energy, environment, agriculture, and industry. Burlington, VT. 30 Aug – 2 Sep 1993.

Graham, R.L., English, B.C., and Noon, C.E. 2000. A Geographic Information System-based modeling system for evaluating the cost of delivered energy crop feedstock. Biomass and Bioenergy 18(2000): 309 – 329.

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

Kort, J., Collins, M., and Ditsch, D. 1998. A review of soil erosion potential associated with biomass crops. Biomass and Bioenergy 14(4): 351-359.

Mani, S., Tabil, L.G., Sokhansanj, S. 2004. Grinding performance and physical properties of wheat and barley straws, corn stover and switchgrass. Biomass and Bioenergy 27: 339-352.

Noon, C.E. and Daly, M.J. 1996. GIS-Based Biomass Resource Assessment with BRAVO. Biomass and Bioenergy 10(2-3): 101-109.

Pierce, F. J., Larson, W. E., Dowdy, R. H. and Graham, W.A.P. 1983. Productivity of soils: assessing long-term changes due to erosion. Journal of Soil and Water Conservation. 38(1): 39-44.

Perrin, R., Vogel, K., Schmer, M. and Mitchell, R. 2008. Farm-scale production cost of switchgrass for biomass. Bioenergy and Research 1:91-97.

Tharakan, P.J., Volk, T.A., Lindsey, C.A., Abrahamson, L.P., and White, E.H. 2005. Evaluating the impact of three incentive programs on the economics of cofiring willow biomass with coal in New York State. Energy Policy 33(2005): 337-347.

Timmons, D., Allen, G. and Damery, D. 2008. Biomass Energy Crops: Massachusetts' Potential. Massachusetts Sustainable Forest Bioenergy Initiative.

Varela, M., Lechon, Y., and Saez, R. 1999. Environmental and socioeconomic aspects in the strategic analysis of a biomass power plant integration. Biomass and Bioenergy 17(1999): 405 – 413.

Varela, M., Saez, R. and Audus, H. 2001. Large-scale economic integration of electricity from short-rotation woody crops. Solar Energy 70(2): 95-107.

Voivontas, D., Assimacopoulos, D., and Koukios, E.G. 2001. Assessment of biomass potential for power production: a GIS based method. Biomass and Bioenergy 20(2001): 101-112.

Walsh, M.E., De La Torre Ugarte, D.G., Shapouri, H., and Slinsky, S.P. 2003. Bioenergy crop production in the United States: Potential quantities, land use changes, and economic impacts on the agricultural sector. Environmental and Resource Economics 24: 313-333.

Wojnar, Z., Van Nostrand, J.M. and Rutzke, C.R. 2009. Renewable fuels roadmap and sustainable biomass feedstock supply for New York: Draft Final Report. Prepared for the New York State Energy Research and Development Authority.

Other Data Sources

Environmental Protection Agency – Office of Atmospheric Programs. 2007. eGRID2006 Version 2.1 (Emissions and Generation Resource Integrated Database).

National Atlas of the United States. 2005. Atlas.Atlas_Federal_Lands. Reston, VA.

NYS Department of Environmental Conservation. 2008. DEC Lands – NYS (NYSDEC). Albany, NY. <http://www.nysgis.state.ny.us/gisdata/inventories/details.cfj?DSID=1114>.

NYS Office of Cyber Security and Critical Information Coordination. 2009. NYS Streets vector file (Statewide – Streets Public). Albany, NY. Obtained from <http://www.nysgis.state.ny.us/gisdata/inventories/details.cfm?DSID=932>.

USDA Forest Service. The National Atlas of the United States of America. 2000. Forest Cover Types. Obtained from <http://www.nationalatlas.gov/mld/foresti.html>

USDA - NATIONAL AGRICULTURE STATISTICS SERVICE'S 1:100,000-SCALE 2002 CROPLAND DATA LAYER, A Crop-Specific Digital Data Layer for New York, 2006 January 01

USDA – National Agriculture Statistics Service. 2007.

USDA – National Agriculture Statistics Service. 2008.

US Deparment of Commerce, US Census Bureau, Geography Division. 2007. 5-Digit ZIP Code Tabulation Area (ZCTA5). Obtained from <http://www.census.gov/geo/www/tiger>.

USGS EROS Data Center. 1999. 7.5-Minute Digital Elevation Model. Sioux Falls, SD. Obtained from <http://seamless.usgs.gov/website/seamless/viewer.htm>