APPENDIX E:
ANALYSIS OF SUSTAINABLE FEEDSTOCK PRODUCTION POTENTIAL IN NEW YORK STATE

RENEWABLE FUELS ROADMAP AND SUSTAINABLE BIOMASS FEEDSTOCK SUPPLY FOR NEW YORK
Final Report

Submitted to
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NEW YORK DEPARTMENT OF AGRICULTURE AND MARKETS
and
NEW YORK DEPARTMENT OF ENVIRONMENTAL CONSERVATION

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ABSTRACT

An integrated geospatial analysis was performed to determine the potential for sustainable biomass feedstock production on agricultural and forest lands throughout New York State. Suitable and available lands for biomass feedstock production were identified, and the current standing biomass and harvest rates of forests, crops, and agricultural and forest residues was quantified. Best practices for producing sustainable feedstocks were defined. Numerous criteria were used to ensure that feedstock production would be sustainable, including the use of perennial vegetation, maintaining current agricultural and forest production, minimizing emission of greenhouse gases, and reducing offsite movement of nutrients.

New York State could dedicate between 1.0 and 1.7 million acres of non-forest land for bioenergy feedstock production**.** The lower estimate assumes that no crop land is used for new bioenergy feedstock production, instead abandoned farmland, old pasture, and scrub and shrub lands are used. The higher estimate assumes that 0.7 million acres of crop and hay land would become available by the year 2020 due to projected increased crop and milk yields such that the same amount of crops and milk can be produced as in 2007, but on less land. All estimates assume that only half of New York land owners would be interested in using their forest and non-forest land for bioenergy feedstock production and that the other half of land owners might prefer to use the land for uses such as wildlife habitat and recreation. Even so, this proportion varies among counties, with higher rates in more rural counties and lower rates in more urban counties. For land that is currently in non-forest cover, two representative types of feedstocks were included in the scenarios (1) warm-season perennial grasses such as switchgrass, and (2) short-rotation willow.

The Roadmap modeling analysis includes three scenarios. Scenario 1 represents rapid development of a lignocellulosic biofuels industry, circa 2020-2030. All land currently in food production was excluded in this scenario. Potential feedstock production is estimated to be as follows (millions of dry tons): Hardwood chips 3.44, softwood chips 1.37, warm-season grasses 2.28, short-rotation willow 2.06, and corn stover 0.25. Wood chips would be from well-managed harvests primarily of low-value wood from existing forests. The grasses and willow would use 0.98 million acres of land currently in herbaceous cover not required to meet current agricultural needs.

Scenarios 2 and 3 represent very rapid development of a lignocellulosic biofuels industry, circa 2020-2030, requiring very equally swift advances in feedstock production and conversion technologies. The land base for feedstock production is greater because of the use of cropland, as described, above. Potential feedstock production is estimated to be as follows (millions of dry tons): Hardwood chips 4.70, softwood chips 1.72, warm-season grasses 4.59, short-rotation willow 3.32, and corn stover 0.25. The grasses and willow would use 1.68 million acres of land currently in herbaceous cover that is not required to meet current agricultural needs.

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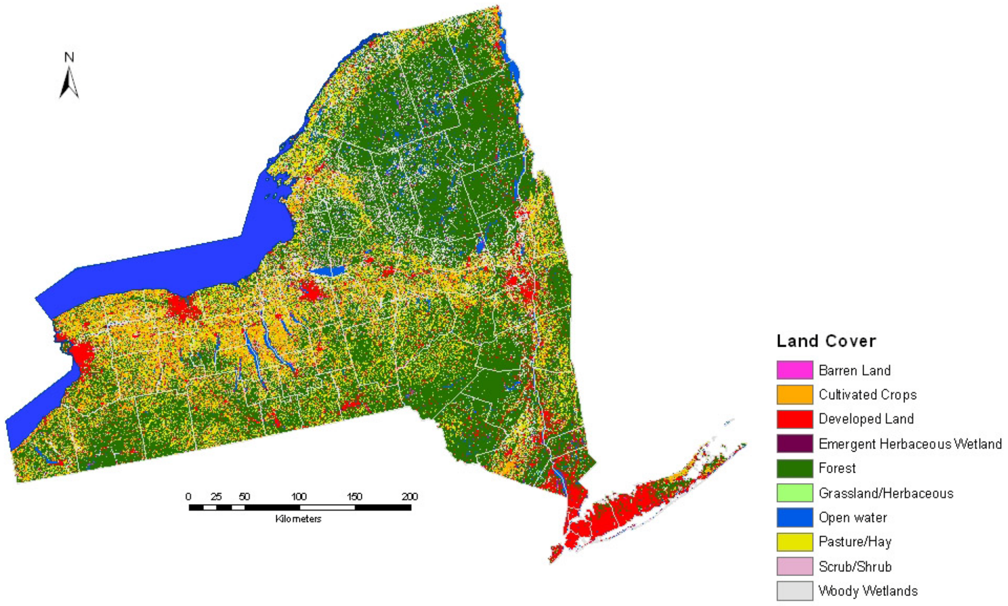
1. INTRODUCTION

To understand the potential for biofuel production in New York State, it is critical to understand the land resource base and current land uses. Taking into account various competing uses for land, the potential production of selected biomass feedstocks is evaluated. This section of the report provides an overview of these topics and describes how the feedstock team developed estimates of how much land could be used for new feedstock production and what yield (biomass, mass/acre) can be expected for key feedstocks on different types of rural land. Many portions of our analysis were geospatial. In order to provide information to the other Roadmap team members, the feedstock team developed estimates for each county in New York State. This was critical in order to examine the potential for biofuel production throughout the State. In this appendix (Appendix E), the feedstock team summarizes the county-scale estimates for the entire State. This is for ease of presentation, and also because the estimates are not designed to support analysis for single counties, but rather for the entire State and portions of the State. Feedstock production potential in neighboring states was not analyzed. This Appendix describes the methods and results used to estimate potential feedstock production. In some cases, additional details are presented in additional sub-appendices, as are some topics that are not addressed in the main body of this Appendix (see Table of Contents).

2. LAND COVER AND LAND USE IN NEW YORK STATE

The most fundamental resource is the land base, and the feedstock team began its analysis by examining what kind of land the State has now and how it is being used. The term “land cover” means different kinds of vegetation or built environment on the land – what can be seen by the eye or from remote sensing. The term “land use” means how the land is being used, which can sometimes be inferred by the land cover, but is really a function of the current owner’s use and management of the land. Figure E-1 shows the current land cover in New York State. The data are from the National Land Cover Database (NLCD), a multi-agency effort to analyze land cover throughout the U.S. The information is derived from satellite imagery circa 2001, combined with survey information on land use. The NLCD estimates were selected as a starting point for our analysis because they are comprehensive, covering all land cover types, and all areas of the State. However, for specific aspects of the analysis additional data were used. For example, to estimate forest feedstock production potential, data from the United States Department of Agriculture (USDA) Forest Service (specifically, Forest Inventory and Analysis (FIA)) were used. Forest covers approximately 54% of New York State, based on the NLCD (Table E-1). The next largest land use in the State is agriculture. Lands used for pasture, hay, and grasslands comprise about 15% of the land. Row crops cover nearly 9% of the State. Land that has been developed also comprises nearly 9% of the State. New York wetlands cover approximately 8% of the State, while open water accounts for 3% of the State. Shrub and scrub land also account for about 3% of the total.

Figure E-1. Land Cover in New York State, based on the 2001 National Land Cover Database.



Source: National Land Cover Database (NLCD) 2001 (http://www.mrlc.gov)

Table E-1. Current Land Cover and Land Use in New York State

Land Cover Type (From NLCD)[1]	Land Area (acres)	Land Area (%)	Current Crop, Forage, and Hay Land Use[2] (acres)	Current Equine Land Use[3] (acres)
Forest Land[4]	16,702,133	53.7 %		
Pasture, Hay & Grass Land	4,612,554	14.8 %	1,962,620	987,000
Developed Land	2,708,501	8.7 %		
Crop Land	2,641,314	8.5 %	1,707,577	
Wetlands	2,453,891	7.9 %		
Open Water	1,017,873	3.3 %		
Shrub/Scrub Land	878,170	2.8 %		
Barren Land	58,608	0.2 %		
Other	6,044	0.02 %		
TOTAL	**31,079,088**	**100%**	**3,670,197**	**987,000**

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[1] These land use categories are aggregated from the National Land Cover Database (Homer et al. 2007).

[2] Land use categories are from the 2007 Census of Agriculture (NASS 2009). Crop land includes grains, oilseeds, vegetables, and fruit. Forage land includes all forages used for livestock. Hay includes all types.

[3] Equine land includes all land used for horses, data are from (Ropel & Smith 2007).

[4] The value presented here for forest land is derived from the NLCD and is based on the area of forest cover in rural parts of the state. This database was used as a starting point for analysis of land cover. However, more detailed data on forest area are available based on survey data from the USDA Forest Service (Forest Inventory and Analysis (FIA) program), which conducts surveys of forests in cooperation with State agencies. For analysis of forest feedstocks, these more detailed FIA data were used.

3. CURRENT FOREST AND AGRICULTURAL PRODUCTION

Most of New York forest land is in private ownership (77%), and 90% of this private land is classified by the USDA Forest Service as "timberland," meaning that it is suitable for sustainable harvest management[1]. Most of the remaining forest is classified as "reserved," meaning that it is not available for timber production. Total annual forest production in 2007 was 161 million cubic feet, including 635 million board feet[2] of logs, 1.1 million wet (green) tons of pulpwood and 1.1 million wet tons of wood chips (NYSDEC 2008). This total equates to approximately 2.3 million dry tons of biomass removed per year. In addition, substantial quantities of firewood are harvested from New York forests, estimated to be an additional 1.56 million dry tons per year (personal communication -- Sloane Crawford, NYSDEC). Since 1999, the annual harvest of logs has decreased from 900 million board feet to 635 million board feet, while pulpwood and chip harvests have been variable with no strong trends. Some of this harvested wood later becomes residue after milling or manufacturing. Modeled estimates of forest biomass based on the 2002-2006 Forest Inventory and Analysis (FIA) Database and 2007 Timber Products database of the USDA Forest Service show that New York forest biomass is growing approximately three times faster than it is being harvested.

Current agricultural land use and production of selected crops in 2007 is summarized in greater detail in Table E-2. In terms of acreage, forage and hay use the most land (nearly 2 million acres), followed by corn grain (551,629 acres) and corn silage (507,568 acres). Soybean is grown on 199,755 acres. Small grains use 1.6% of the land and orchards and vegetables use 1% of the land. In terms of total production, the greatest production is corn silage (3.8 million dry tons per year) followed by corn grain (1.7 million dry tons per year). There are approximately equal amounts of dry matter in corn grain as in the remainder of the above-ground portion of the plant. Thus, there are about 1.7 million tons of corn stover produced each year in addition to the corn grain. However, in general, corn stover is not a product, so it is not included in agricultural statistic summaries. To maintain soil cover, reduce the risk of erosion, and return organic matter to the soil, a portion of the total corn stover production should be returned to the soil in actual practice. Accordingly, lower levels of availability are estimated for future potential sustainable biomass feedstock production as discussed below. Soybean production is nearly 0.2 million dry tons per year. Sorghum and sunflower are potential bioenergy feedstocks that are grown in the State but only small quantities are currently produced.

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[1] (http://www.fs.fed.us/ne/fia/states/ny/index.html)

[2] The amount of wood contained in an unfinished board one inch thick, one foot long, and one foot wide.

Table E-2. Current Agricultural Production (Derived from the 2007 Census of Agriculture)

Commodity	Area Harvested	Average Yield	Yield Unit	Production Weight	Moisture Content	Production Dry Weight	Percentage of Current NY Biomass Total (dry weight basis)
	acres		*per acre*	*Wet short tons*[2]	*% moisture*	*Dry short tons*	%
Corn (grain, stover and silage)[1]						**7,268,611**	60.6%
Corn Grain	*551,629*	*129.5*	*bushel*	*2,000,720*	*15.5%*	*1,690,608*	
Corn Stover [1]						*1,690,000* [1]	
Corn Silage	*507,568*	*17.0*	*tons*	*8,640,006*	*55.0%*	*3,888,003*	
All Forage + Hay	1,962,620	2.5	tons	4,981,812	13.0%	**4,334,176**	36.1%
Soybeans	199,775	37.3	bushel	223,700	13.0%	**194,619**	1.6%
Vegetable/Orchard	264,495						
Wheat	84,955	53.5	bushel	136,321	13.5 %	**117,918**	1%
Oats	60,999	58.3	bushel	56,900	14.0%	**48,934**	0.4%
Sorghum (grain and silage)						**11,030**	0.1%
Sorghum Grain	*717*	*49.9*	*bushel*	*1,003*	*13.0%*	*873*	
Sorghum Silage	*3,192*	*7.1*	*tons*	*22,571*	*55.0%*	*10,157*	
Barley	10,793	49.1	bushel	12,730	14.5%	**10,844**	0.1%
All other Beans[3]	16,218	1530	pounds	12,388	13.0%	**10,778**	0.1%
Rye	6,879	32.7	bushel	6,303	14.0%	**5,421**	0.05%
Sunflower seed	357	1,030	pounds	184	10.0%	**166**	0.001%
TOTAL (no stover)	3,670,197					**10,312,497**	
TOTAL*	**3,670,197**					**12,002,497**	100 %

[1] Corn stover (above ground portion of the plant that is not grain) is approximately equal to the dry weight of the grain but is not included in the Census of Agriculture. Corn stover weight is estimated here from corn grain data. The amount of corn stover shown here is the maximum produced and does not consider amounts that would be left behind to replenish soil in actual practice.
[2] All tons are short tons.
[3] All beans other than soybeans.

The dominant biomass feedstock used currently to produce biofuels in New York State is corn grain. It is used at a single ethanol production facility in Shelby, NY. This facility reports that it uses 18.5 million bushels of corn grain per year. This amount is equivalent to 26% of current corn grain production, although not all of the grain used by the plant is necessarily grown in New York State. Another corn ethanol facility has been constructed in Volney but is not operating at this writing (February 2010). At its nameplate capacity, this facility would use 35.8 million bushels of corn grain per year, equivalent to 50% of current production. Thus, it is expected that in the near future, the equivalent of 76% of corn grain production in New York State will be used requiring import of corn grain from other states to meet demand for biofuel feedstock, livestock feed, and other needs. When corn ethanol is produced, a by-product is "dry distiller's grains with solubles" (DDGS), which has value as a livestock feed. The amount of DDGS produced is approximately 30% of the weight of the corn grain (Dien et al. 2002 as cited by Dien et al. 2008). Because DDGS has a different nutrient content than corn grain, it must be added to livestock diets in limited amounts, which vary by type of livestock, and balanced with other feeds. On the other hand, it has higher protein content than corn grain. With a recommended milking cow diet of six pounds of DDGS per day (13.2% of the total diet, Dr. Larry Chase, personal communication) , 58% of the New York State dairy herd potentially could use all of the DDGS resulting from the two ethanol plants (390,010 oven dry tons, or odt). Assuming continued current corn grain import levels, this amount of DDGS (and no liquor DDGS) would displace the need for 238,659 New York acres used for producing a fraction of current alfalfa silage (8.0%), corn silage (1.5%), corn grain (35.3%), and soybean meal (38.0%). This total area (238,659 acres) is 43% of the area currently used for corn grain production in New York State. Thus the two corn ethanol plants operating at nameplate capacity would use the equivalent of 32% of current (2007) corn grain acreage in New York State, after accounting for the acreage represented by the potential feed value of the DDGS for dairy cattle. It should be noted that these calculations are of the overall net value for the State; in reality, the corn ethanol facilities are unlikely to obtain all of their corn from within New York State.

4. ESTIMATING BIOMASS PRODUCTION CAPACITY FOR SCENARIO ANALYSIS

The Roadmap modeling analysis includes three scenarios. These scenarios assume that substantial land is available for bioenergy feedstock production. They also assume that a relatively high intensity production system is used to maximize feedstock yields, similar to what is currently used in crop agriculture. Despite the focus on maximizing production, environmental constraints are also used to ensure that this production is sustainable both economically and environmentally. These scenarios are described briefly below.

4.1 CURRENT CAPACITY FOR BIOFUEL PRODUCTION

The Roadmap team assumed that the existing grain ethanol facilities in New York (capable of producing 154 million gallons per year (MGY) operating at full capacity) will continue to produce biofuels in 2020. It was assumed that there would be no growth beyond that current capacity for grain-based ethanol. One of those facilities is not operating now but is scheduled to come on line in the near future. For 154 MGY, the equivalent of 76% of the current corn grain crop would be required. All of the scenarios (below) represent additional development of cellulosic ethanol beyond this current capacity.

4.2 SUSTAINABILITY CONSIDERATIONS FOR SCENARIO DEVELOPMENT

To ensure that feedstock production in New York State is sustainable, a number of choices were made about the types of land, types of feedstocks, and types of harvest that would be included in the three scenarios. An overview of these choices and constraints is presented in the following sections, and further details are presented in subsequent sections of this Appendix.

4.2.1 Sustainability Considerations for Land Use for Bioenergy Feedstocks

To estimate the area of land that was (1) suitable and (2) potentially available for energy feedstock production, the following assumptions were made:

- New York forests will stay forests. The scenarios do not convert any forest lands to non-forest lands (see further considerations for forests in Appendix E-E).
- Lands currently in herbaceous cover (pasture, hay, grassland, crop land, shrub and scrub land) will remain in herbaceous cover, including bioenergy crops.
- Not all lands in herbaceous cover are practical to access for harvest. The scenarios remove from consideration all acreage that is in fields of less than five acres and also remove acreage that would be difficult for farm machinery to access (slope greater than 15%).
- Areas of land in federal ownership and State protected lands were removed from consideration.
- Areas currently in equine use will remain in equine use and were removed from consideration.
- Some cropland is currently idle and fallow. This land is assumed to be available for feedstock production.
- Not all landowners will want to use their lands for energy feedstock production. The percentage of landowners potentially participating in feedstock production in each county was modeled based on population density.
- Crop yield per acre will increase in line with current trends, and milk yield per cow will increase in line with current trends. These increases in production efficiency will allow today’s crop and dairy production levels to occur on less total land in the future. For Scenario 1, this land can be used for increased crop production. For Scenarios 2 and 3, this land could be dedicated to production of perennial bioenergy feedstocks while maintaining agricultural production at 2007 levels. Thus, across scenarios, agricultural production capacity will either increase (Scenario 1) or, at a minimum, remain constant at 2007 levels (Scenarios 2 and 3).
- Crop residues are valued for uses like animal bedding. For this reason, no small grain straw was assumed to be available for use as a bioenergy feedstock. Crop residues can be

suitable bioenergy feedstocks, but it is important to leave residue on the soil surface to prevent erosion. Therefore, the amount of corn stover that could be removed was limited to no more than 25% from a given field, and further limited to only half of all corn grain fields.

4.2.2 Sustainability Considerations for Selection of Feedstocks on Herbaceous Land

For land that is currently in herbaceous (non-forest) cover, two representative types of feedstocks were included in the scenarios (1) warm-season perennial grasses such as switchgrass (grasses), and (2) short-rotation willow (henceforth willow). Neither of these feedstocks is a food crop; instead, we refer to them as dedicated bioenergy feedstocks. Both of these feedstocks are perennials, which have many advantages over annual crops for feedstock production. Properly managed perennials have the potential for high yields with relatively low environmental impacts. Perennial vegetation can provide valuable wildlife habitat and cover throughout many seasons of the year. Because there is vegetation present throughout the entire year, the risk of erosion and off-site transport of nutrient and sediments in surface flow is also greatly reduced compared to annual crops. Additionally, perennials, which are not plowed annually, retain root systems that store carbon in the soil, providing benefits to soil health as well as potentially sequestering carbon. Leaching and volatilization of nitrogen is also greatly reduced compared to annuals because roots are present all year around.

4.2.3 Sustainability Considerations for Harvest of Woody Biomass from Forests.

Estimates of woody biomass available from New York's forests incorporated a number of restrictions to ensure that existing wood product industries were not impacted, environmental concerns were addressed, and annual yields were sustainable. These restrictions included:

- Prohibiting harvesting in the forest preserve and other protected areas,
- Ensuring that current levels of harvesting for traditional forest products were maintained,
- Limiting forest harvest so that it never exceeds the net annual growth rate of forests in each county,
- Limiting the proportion of tops and residues collected and prohibiting collection of standing dead trees to address concerns related to nutrient depletion and biodiversity,
- Applying a sustainable yield model to address concerns related to site conditions, future demographics, or potential development that might impact long term sustained yield management.

Details of these restrictions and how they were applied can be found in Appendix E-D, Table E-D-18.

4.3 SCENARIO DEFINITION FROM A FEEDSTOCK PERSPECTIVE

The Roadmap team created three possible future scenarios (~2020 to 2030) of biofuel industry expansion in New York State in order to frame the analysis of the potential biofuel industry impacts. The three scenarios are not meant to be recommendations, but rather allow a broad consideration of the primary benefits and challenges expected to arise from a large expansion of a biofuels industry in New York State. Below is an introduction of these scenarios.

4.3.1 Scenario 1 - "Big Step Forward"

This scenario represents rapid development of a lignocellulosic biofuels industry, circa 2020-2030. For this modeling exercise, rapid development of significant lignocellulosic feedstock resources is assumed on a portion of suitable and available rural lands. The available land base excludes all land currently in food production. Potential feedstock production is estimated to be as follows (millions of dry tons): Hardwood chips 3.44, softwood chips 1.37, warm-season grasses (grasses) 2.28, short-rotation willow (willow) 2.06, and corn stover 0.25. Wood chips would be from well-managed harvests primarily of low-value wood from existing forests. The grasses and willow would use 0.98 million acres of land currently in herbaceous cover that is not required to meet current agricultural needs. Conversion technology is assumed to have met the cost and performance expectations for the *first generation* of lignocellulosic biorefineries (biochemical and thermochemical systems).

In each scenario, the base case is the lower fuel price sensitivity case - unsubsidized direct competition with petroleum-based fuels. In this scenario's base case, four lignocellulosic biorefineries could be profitably built and produce ethanol for a total New York production capacity of 354 MGY. Sited at the center of resource producing regions, the average capacity of each site is near 90 MGY. In addition, in all scenarios the Roadmap team assumes that the current corn ethanol capacity in New York continues to operate profitably, adding 154 MGY of grain ethanol. Total New York production of renewable gasoline substitutes would reach 508 MGY and New York could meet approximately 5.6%[3] of its transportation gasoline consumption with home grown biofuels.

4.3.2 Scenario 2 - "Giant Leap Forward"

This scenario represents very rapid development of a lignocellulosic biofuels industry, circa 2020-2030, requiring very rapid advances in feedstock production and conversion technologies. The land base for feedstock production is greater because of the use of cropland, but only cropland estimated to become available due to increases in crop yield and milk yield per cow such that current (2007) crop and milk production could be maintained. Potential feedstock production is estimated to be as follows (millions of dry tons): Hardwood chips 4.70, softwood chips 1.72, warm-season grasses 4.59, short-rotation willow

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[3] 508 MGY ethanol * 0.657 gasoline equivalents / 6,048 MGY (projected 2020 consumption) = 334 MGY gasoline equivalents, which is 5.6% of 2020 forecast consumption.

3.32, and corn stover 0.25. Wood chips would be from well-managed harvests primarily of low-value wood from existing forests, with greater overall harvest than in Scenario 1, but still meeting sustainability criteria summarized above and detailed below. The grasses and willow would use 1.68 million acres of land currently in herbaceous cover that is not required to meet current agricultural needs. The *second generation* lignocellulosic biorefineries (biochemical and thermochemical systems) are assumed ready for commercial deployment.

In this scenario for the base case, (unsubsidized direct competition with petroleum-based fuels) ligno-cellulosic biorefineries producing ethanol at a total production capacity of 1,295 MGY could be built and operated profitably, amounting to four times the capacity projected for Scenario 1. The production units modeled are to be built at the same four sites in Scenario 1 and average capacity at each site is near 325 MGY. The biorefinery would draw from the biomass resources within the supply shed, typically within a radius of ~ 100 miles. In effect, the model predicts that, with the advanced conversion technologies, all of the available sustainably-harvested biomass resources would be consumed in production. This level of production is very unlikely to occur by 2020 or 2030 because of competition for resources and because it would presumably take a long time to build the infrastructure to supply these facilities. In addition, constraints for site permitting, competition for resources, and logistical issues would further limit the actual capacity built. There could be very large conversion systems or more likely multiple units operating at the same site (e.g., two 150 MGY units provide 300 MGY of total capacity). Total New York production of renewable gasoline substitutes including the grain-derived ethanol would reach 1,449 MGY and New York could meet approximately 16% of its transportation gasoline consumption with home grown biofuels. [4]

4.3.3 Scenario 3 - "Distributed Production"

This scenario envisions the same feedstock production and technology performance as Scenario 2. However, it is a distributed industry with no biorefinery capacity exceeding 60 MGY, except for the existing grain ethanol biorefineries. While ethanol facilities currently in the planning stages are reaching the 300 MGY mark, the plant size was constrained to 20% of that scale in order to draw upon local biomass resources (typically a 50-mile radius) and to serve local markets or blending terminals. While smaller facilities are usually disadvantaged by both the economies of scale in physical plant and development costs, they represent a smaller overall financial commitment and tend to have proportionately lower impacts on local communities such as road traffic congestion. This level of production is very unlikely to occur by 2020 or 2030 because of competition for resources and because it would presumably take a long time to build the infrastructure to supply these facilities as described for Scenario 2.

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[4] 1,449 MGY ethanol * 0.657 gasoline equivalents / 6,048 MGY = 952 MGY gasoline equivalents, which is 16% of 2020 forecast consumption.

4.4 IDENTIFYING SUITABLE AND POTENTIALLY AVAILABLE LAND FOR FEEDSTOCK PRODUCTION USED IN SCENARIO ANALYSIS

The first step in estimating feedstock production potential is to determine the amount and type of land that could be available for dedicated feedstock production. We assume that there will not be any conversion of land from forest and to production of dedicated biomass feedstocks or crops. Thus, we examine the potential sustainable production of herbaceous feedstocks and willow on lands that are currently in herbaceous cover. For forestland, we examine the potential for increased sustainable production of wood from existing mixed-species forests.

For herbaceous land, the overall process is summarized in Table E-3. To calculate the amount of land that could be available in coming decades for dedicated grasses and willow bioenergy feedstocks, we began with the sum of the crop, pasture, grass & hay land from the NLCD (Table E-3, leftmost column of data) . Then we calculated the fraction of this land that would be biophysically suitable for feedstock production. Suitable Land was defined as (1) slope less than 15%, (2) individual field area greater than 5 acres, and (3) land not in federal ownership or in State protected lands. The slope factor of 15% was selected because steeper slopes are not suitable for typical farm equipment. Areas exceeding this slope value are shown in Figure E-2. The field size of five acres was selected because smaller fields are not suitable for large-scale commercial feedstock production operations. It was assumed that in order to achieve high yields at viable costs, 2020-2030 feedstock production operations would use larger fields and larger equipment. Areas of land in federal ownership that were removed from consideration are shown in Figure E-3.

Figure E-2. Land in New York State with Slope Greater Than 15%.

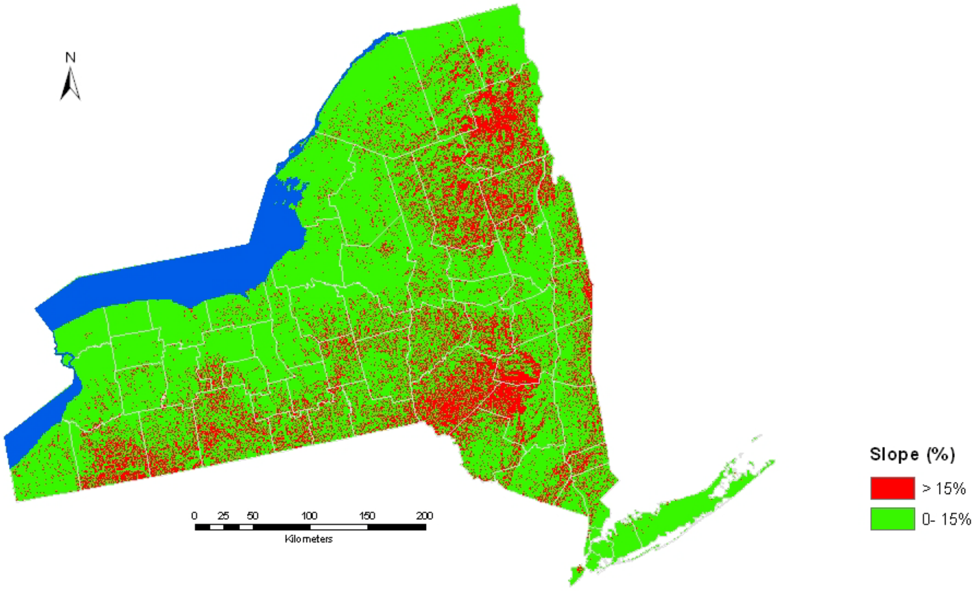
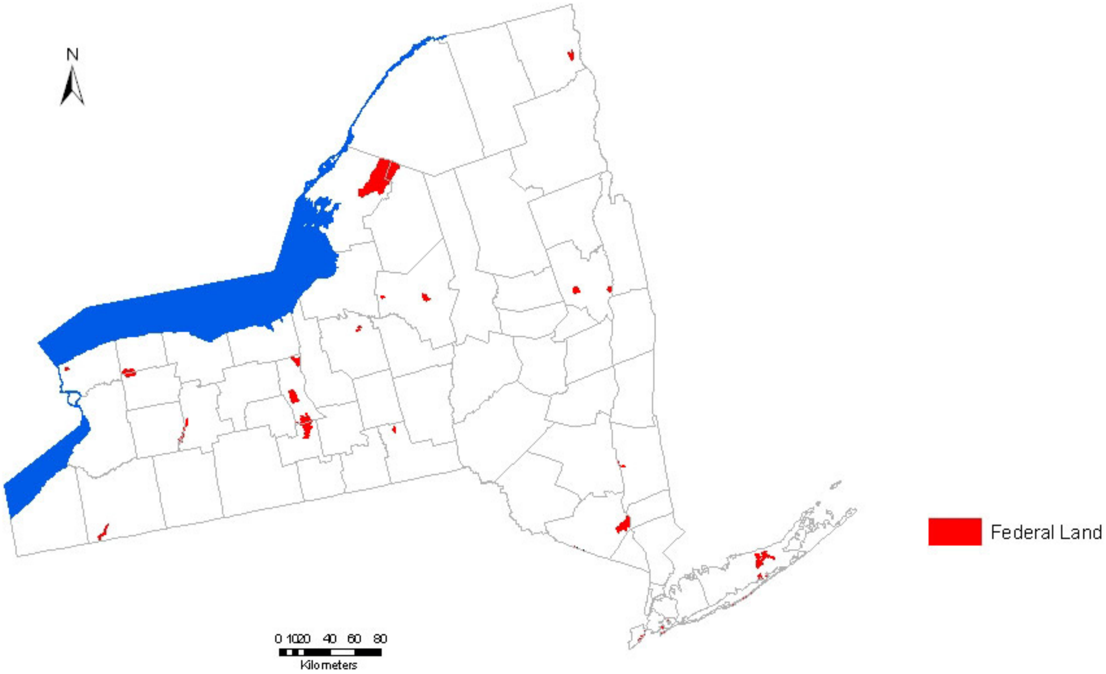


Figure E-3. Federal Land Removed from Consideration in New York State.



NOTE: Data are from the geospatial data set in the National Atlas (http://www.nationalatlas.gov/mld/fedlanp.html).

Table E-3. Scenario 1: Current Land Cover and Land Use in New York State, and Potential Area for New Bioenergy Feedstocks.

Land Cover Type (from NLCD)[1]	Land Area	Suitable Area (not Federal, slope < 15%, field > 5 acres)	Current Crop, Forage, and Hay Land	Current Equine Land Use	Unavailable due to owner preferences	Available Area (our calculation)
	acres	*acres*	*acres*	*acres*	*acres*	*acres*
Crop Land	2,641,314	2,422,795	1,707,577	0	715,218	0
Pasture, Hay & Grass Land	4,612,554	4,144,010	1,962,620	987,000	585,454	608,936
Shrub & Scrub Land	878,170	704,458	0	0	331,822	372,637
Forest Land	16,702,133	15,775,600	0	0	n/a	n/a
Developed land	2,708,501	0	0	0		0
Barren land	58,608	0	0	0		0
Wetlands	2,453,891	0	0	0		0
Open water	1,017,873	0	0	0		0
Other	6,044	0	0	0		0
TOTAL	**31,079,087**	**23,046,864**	**3,670,197**	**987,000**	**1,632,494**	**981,572**

[1] NLCD is the National Land Cover Database, derived from remote sensing imagery circa 2001.

We estimate that 981,572 acres of New York land is suitable and potentially available.[5] Equine use is handled separately from agricultural use because not all horses are on farms as defined by the Census of Agriculture. Lastly, we removed a fraction of land because not all owners will choose to produce biomass feedstock on their land, even if it is not currently in agricultural or equine use. Because landowners have a wide variety of goals and uses for their land (hunting, aesthetics, etc.), we assume that approximately half of suitable and available rural herbaceous land might be used for feedstock production. We also assume less land will be used in more populated counties. For shrub and scrub land, we again assume that approximately one-half of suitable land might be used by owners for bioenergy production. This percentage of land-owner participation varies by county; the algorithm is discussed in Appendix E-D.

For cropland and hay land, there is another step in the calculations. In order to mitigate concerns about competition between renewable fuels and food for land, the model for all scenarios maintains current

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[5] This number was derived by subtracting the land currently in agricultural or equine use from the total amount of suitable land.

agricultural production. However, since crop yields will increase over time, the same amount of agricultural production can occur on less land, making some current agricultural land available for biomass production in coming decades. Similarly, since milk yield per cow will increase over time, the same amount of production can occur on less land, making additional crop and hay land available. For the New York dairy industry, projections for the future suggest that current milk production may be maintained, but that there may not be markets for increased production (Ladue et al. 2001). This land could be used for increased agricultural production or it could be used for bioenergy production while maintaining current (2007) agricultural production. Based on regression analysis of historical trends in crop yield and in milk yield per cow, the future increase in crop and milk yields was projected for the year 2020. Different assumptions about the availability of crop land are made in the different scenarios. In Scenario 1, no cropland is assumed to be available for dedicated bioenergy feedstock production (Table E-3). Still, in Scenarios 2 and 3, some current hayland and cropland is available, as described above and shown in Table E-4. In addition, some crop land is currently idle and fallow, and we assume that such land is available for feedstock production. A breakdown of some of these categories of land is shown in Table E-4.

Table E-4. Scenario 2 & 3: Sources of Available Land for New Grass and Willow Feedstock Production in New York State.

Land Type	Land Area Suitable and Available
	acres
Cropland (idle, fallow, or available due to increased crop and milk yield)	715,219
Hayland (increased milk yield/cow)	126,962
Miscellaneous herbaceous land (not on farms; not used for horses)	481,817
Shrub/scrub land (not used for horses	356,483
TOTAL	**1,680,481**

5. MODELING PRODUCTION POTENTIAL OF KEY FEEDSTOCKS

5.1 SELECTION OF KEY FEEDSTOCKS FOR ANALYSIS

We evaluated crop residues, dedicated annuals on agricultural land, and biomass from existing forests. The significant crop residues in New York State are corn stover and small-grain straw. Small-grain straw is highly valued for various purposes including bedding for horses. For this reason we estimate that no significant amount of straw will be available as a bioenergy feedstock. Corn stover is not highly valued and is a potential feedstock. However, corn stover provides value on the soil surface to prevent rain splash, reduce erosion, and to return organic matter to the soil. To maintain soil quality we conservatively estimate 25% of corn stover on a field could be removed as a feedstock. However, due to climatic and operational considerations, it is not practical to obtain all of this material from the field after corn harvest, so we assume that only 12.5% of all corn stover will be available as a feedstock. In practice, the rate of corn stover return to soil should be based on site-specific factors including soil texture, slope, and tillage practices. Efforts are underway at the national scale to link modeling with experimentation to improve estimates of the amount of corn stover that can be harvested without degrading soil quality.

A second category of feedstocks is hardwood and softwood from existing forests. This category includes residues from existing harvests, residues from wood processing facilities, non-commercial species, and commercial species. By commercial species, we mean forest tree species that are valued for wood products including lumber, flooring, etc. We analyze the availability of this material based on forest inventory data as described in the Section 5.4.

A third category of feedstocks is annuals, herbaceous perennials and short-rotation woody crops that could be grown on current agricultural land (see Scenario 2 description of limited cropland use) or other transition land in herbaceous cover types. There are many potential feedstocks that could be grown in New York State. We focus on two representative types of feedstocks (1) warm-season perennial grasses such as switchgrass, and (2) short-rotation willow. Neither of these feedstocks is a food crop; instead, they are dedicated bioenergy feedstocks. Both of these feedstocks are perennials, which have many advantages over annual crops for feedstock production. Properly managed perennials have the potential for high yields with relatively low environmental impacts. Because there is vegetation present throughout the entire year, the risk of erosion and off-site transport of nutrient and sediment in surface flow is greatly reduced compared to annual crops. Additionally, perennials store carbon in the soil, providing benefits to soil health as well as potentially sequestering carbon. Leaching and volatilization of nitrogen is also greatly reduced compared to annuals because roots are present all year. This is particularly important in the early spring when nitrogen becomes available due to soil processes (mineralization and nitrification). At this critical time period, annuals such as corn do not yet have well-established root systems, and cannot take up all of the available nitrogen (see Appendix E-F). However, perennials do have established roots systems and will be able to take up much more of the available nitrogen, resulting in more efficient uptake and lower nitrogen losses to the environment (leaching, volatilization, and denitrification). Perennials are more efficient users of nitrogen and reduce environmental impacts of nitrogen loss to surface water, ground water, or to the atmosphere. Further information is found in Appendix E-F.

For grasses, substantial research elsewhere in the U.S. and ongoing research in New York State demonstrates that switchgrass for example, under good management and using current hay equipment, can produce high yields (See Appendix E-B). High yields are critical in order to produce large quantities of biomass feedstock at an affordable price. For willow, there is a long history of research and demonstration in New York State. In this system, selected varieties of willow are grown in close spacing and are coppiced (cut just above the ground) every three or four years. Research and demonstration at multiple sites in New York have shown that willow can produce high volumes of biomass under good management. Although we focus on warm-season grasses and willow for the modeling portion of the analysis there are many other feedstocks that could play an important role in the future of biofuels in New York State. Further information on some other feedstocks is found in Appendix E-C including cool-season grasses, canola, camelina, and sorghum.

5.2 ALLOCATING LAND BETWEEN WARM-SEASON GRASSES AND WILLOW

After quantifying the available land resource, the next step is to allocate different feedstocks to that land. As discussed above, we assume that forest land will remain forest and herbaceous land will remain in herbaceous cover or short-rotation willow. Thus we need to allocate available herbaceous land to either willow or grasses. Both feedstocks can be grown on many types of soil and can maintain viable stands for decades if properly managed. Willow is tolerant of poorly-drained soils, and may be more suitable for these soils than some warm-season grasses. There are many reasons why a grower or a landowner might prefer grasses or willow. The most critical difference is that the start-up costs for willow are much greater than for grasses. While a willow stand must be maintained for approximately 22 years in order to provide a viable economic return, a warm-season grass stand can provide viable economic return if maintained for only 10 years. This difference should be kept in mind when interpreting results. Thus production costs are modeled differently: willow over a 22-year stand life; warm-season grasses over a 10-year stand life. It is reasonable to assume that more landowners would be willing to commit land for 10 years than for 22 years for this 2020-2030 time frame. Also, without intervention, herbaceous land will revert to shrubs and finally to forest. Thus, land that is currently in herbaceous cover is being managed (mowed) to maintain herbaceous cover (or has been managed that way in the recent past). Therefore, we assume that landowners of herbaceous land have a preference for herbaceous land, while owners of shrub land do not have such a preference. In Scenario 1, somewhat more land is allocated to warm-season grasses (539,809 acres, Table E-8) than to willow (441,764 acres, Table E-7). In Scenarios 2 and 3, more land is allocated to both feedstocks, but the land allocated to grasses (983,898 acres, Table E-11) is still greater than that allocated to willow (696,583 acres, Table E-11). It is very difficult to predict the likely future allocation among such feedstocks, since neither is currently grown to any large extent in the State. As discussed above, both are predicted to have similar potential yields. Genetic improvements in grasses can be planted every 10 years, perhaps advancing its yield over willow in the early development of a biomass feedstock supply chain. However, willow has variable harvesting benefits to respond to fluctuation in supply/demand. Willow is unlikely to be plowed under for an alternate crop in any given year, thus providing a processing plant a reliable source of feedstock for 22 years. Willow is likely to be less expensive to produce when amortized over a 22-year stand life, but grass production may be more cost effective over a 10-year stand life. Also, a conversion facility may prefer one type of feedstock to another. By creating a strong local market, a new facility could certainly influence what feedstocks are produced nearby.

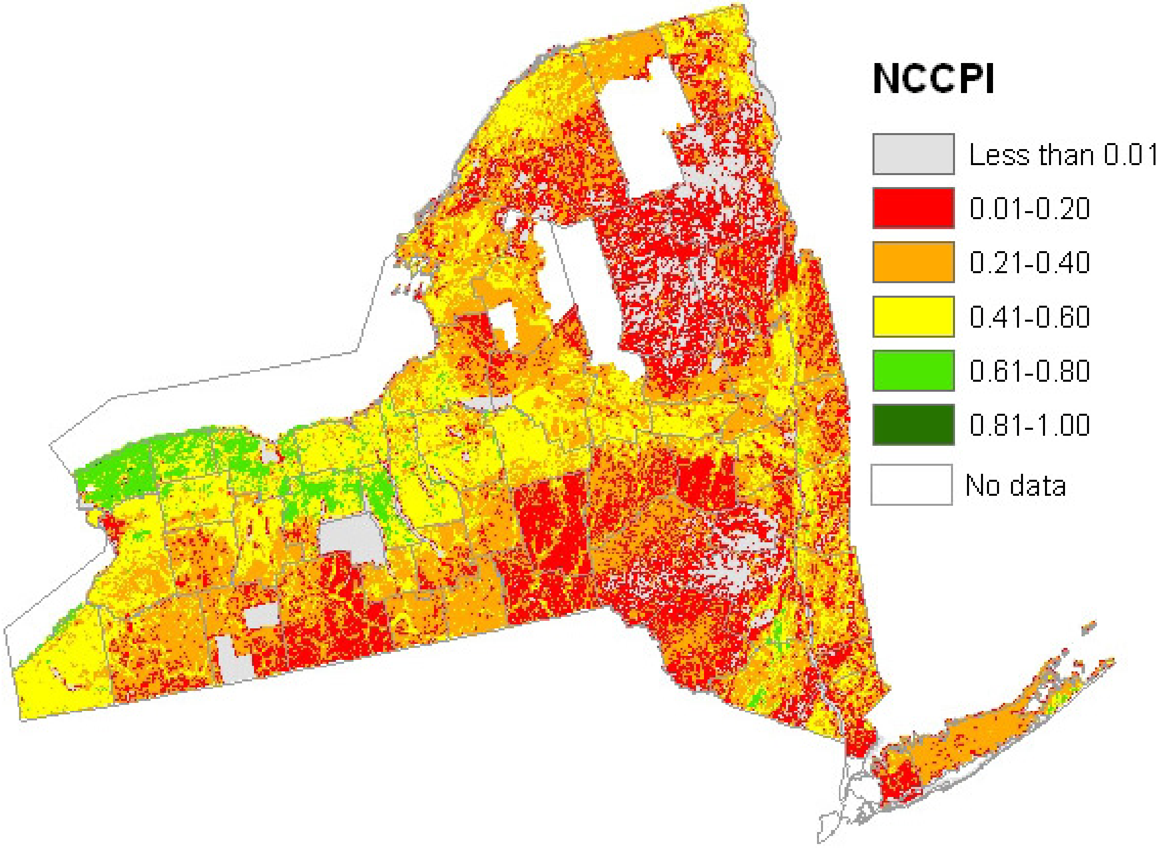
5.3 MODELING THE YIELD OF GRASSES AND WILLOW BASED ON SOIL AND CLIMATE

There are very few yield data for switchgrass and other warm-season grasses in New York State and Northeastern USA. Similarly, there are data for short-rotation willow from only a few sites in New York and neighboring states. While the data from these research sites are invaluable, they are not sufficient at this time to develop a model of production potential for either feedstock over the very wide range of different soil and climatic conditions found throughout New York State. For corn and willow, we did perform detailed physiologically-based simulations using the Precision Nutrient Management (PNM) model for selected sites. The use of this model is described in Appendix E-F. While the PNM model can be used for a number of individual sites, the detailed data required for accurate simulations with this model are not available for all of the soil types and locations where feedstock may be grown. Therefore, the feedstock team required a model system representing a high-intensity crop production system that is used throughout the State on many different types of soil and climate conditions. As discussed above, corn is the most common crop in New York, and is very widely grown throughout the State and the United States. Thus we modeled the potential production of warm-season grasses based upon geospatial data on soil characteristics, climate, and historical yields of corn on different types of soil. Specifically, a statistical model was developed to predict non-irrigated corn yield for agricultural soil types based on land cover, historical yields, soil, and climate factors. Land cover was quantified based on the NLCD (see discussion earlier on land cover).

The National Commodity Crop Productivity Index (NCCPI) is being developed to predict the growth of crops, based on soils and climate data (Dobos et al. 2008). In addition to an overall crop index, separate indices are being developed for corn, soy, wheat, and cotton. The NCCPI is extremely useful for our modeling effort because it integrates important soil characteristics, that influence crop yield, into a single index that can be calculated for nearly all agricultural soil types at nearly all locations. Thus this index provides a robust yet tractable means of predicting crop yield throughout large areas such as New York State. Estimating the effect of different soil types on yield is important because a substantial biofuel industry will use land that is not currently in crop production. In general, this non-crop land is of lower quality and any crop grown on it will yield less than if grown on current crop land. We used the draft

NCCPI for corn to predict the yield of corn, warm-season perennial grasses, and willow. The NCCPI values for land throughout New York State are shown in Figure E-4. NCCPI values range from 0 to 1, with 0 indicating no productivity, and 1 indicating the best productivity.

Figure E-4. Soil Suitability for Crop Growth Represented with the National Commodity Crop Productivity Index.



NOTE: White areas were incomplete as of May 2009.

The NCCPI was not used directly to predict potential yields for corn and grasses. Instead, we calculated the average NCCPI for corn on all crop land in each county and used it as a predictor of average historical yields at the county scale from the National Agricultural Statistical Service (NASS). Specifically, from the NASS data, average corn grain yield was calculated for all counties in the contiguous[6] United States from 1998 to 2007. Because irrigated and non-irrigated yields are not reported separately for all counties, only counties for which less than 5% of the corn acreage was irrigated were selected. NCCPI values range from 0 to 1, with 0 indicating no productivity, and 1 indicating the best productivity. Only counties for which the average NCCPI value on cropland was greater than 0.05 were selected. To predict yield of feedstocks throughout New York State, we developed a statewide geospatial data layer of the NCCPI. Next we quantified the amount of land in each of 10 classes of the NCCPI values for each land cover type within

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[6] Conterminous

each county. Finally, for each feedstock we used the appropriate yield model to predict the yield for each of the 10 classes of NCCPI value. Further information and discussion on yield modeling is found in Appendix E-A.

5.4 MODELING THE PRODUCTION OF WOOD CHIPS FROM EXISTING FORESTS

The potential production of wood chips from existing forests was modeled based primarily on analysis of two databases. The Forest Inventory and Analysis (FIA) database of the USDA Forest Service includes systematic measurements of forest stands throughout New York State based on a stratified sampling protocol[7]. This database permits county-scale estimates to be made of the amount (volume) of trees in various kinds of forests. Standard equations are used to convert volume estimates to biomass estimates. Three categories of wood were modeled, (1) residue from current harvests, (2) non-commercial species (not used for traditional wood products), and (3) commercial species (merchantable wood). In all cases, the goal was to model realistic sustainable yields. Therefore, only a portion of all available material that grows each year was modeled as available for harvest in order to leave material in the forest for other benefits as well as leave many areas un-harvested. Thus, our approach will result in ongoing accumulation of carbon in forests. That is, in all scenarios, the annual growth rate would exceed the modeled harvest rate (for detailed considerations related to forest best management practices [BMPs], see Appendix E-E). The methodology for making estimates is summarized below and details are provided in Appendix E-D.

Our approach began with methods developed by Castellano et al. (2009) to determine woody biomass “technically” available in supply sheds across different regions of New York. Estimates were made for each county using the most recent data available from the USFS FIA and Timber Products Output (TPO) Websites. The FIA data were from inventories conducted in New York from 2002 through 2006. TPO data are from inventories and surveys conducted in 2007. Types of wood included 1) merchantable biomass (<100% net annual growth), 2) noncommercial species, 3) remaining all live biomass, 4) recoverable logging residue, and 5) biomass from other land clearing and agricultural operations. To determine the biomass “potentially” available for Scenarios 1, 2 and 3, this “technically” available land was further restricted by a sustainable yield management (SYM) model. Sustainable yield management is defined as “the ability for an area to be managed in such a manner that would ensure a continuous supply of timber through time” (Vickery et al. 2009). This SYM model uses human population density to predict harvest rates, with higher harvest rates from counties with low population density and lower amounts from counties with high population density. For each category, softwood and hardwood material was estimated separately. This algorithm was also used for assessing land-owner adoption of perennial feedstocks. Further information about our estimates of residue available from forests is presented in Appendix E-D.

The amount of forest area varies depending on the classification system used. Values for forest land from the USDA Forest Service vary from the values for forest cover from the NLCD because of differences in

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[7] Sampling is stratified based on land cover and forest type, http://www.fs.fed.us/ne/fia.

their classifications systems. Based on forest inventory data from the USDA Forest Service, there are over 18.4 million acres of land classified as forest in the State (compared to 16.7 million acres in the NLCD, which does not include forested wetlands, therefore the difference is due to classification). Removing the forest area in parks and preserves leaves 15.8 million acres of timberland where woody biomass could be harvested. There are 991 million oven dry tons (odt) of standing biomass on the timberland across the State. The State-wide net annual growth rate of growing stock on New York timberland (i.e., amount of harvestable biomass added each year through tree growth less the amount lost to mortality) is 9.6 million odt per year (Appendix E-D).

The estimates of 'technically available' woody biomass from New York's forests indicate that more than 8.9 million oven dry tons could be harvested each year (See Appendix E-D for further detail). However, as described below only 57% of this amount is from the "growing stock" value presented above, the rest of it is from non-merchantable species and other types of wood that are not counted as "growing stock". This is a statewide average of 0.57 odt/acre of timberland (15.8 million acres). This amount of harvesting combined with current rates of removal for traditional forest products would not exceed the net annual growth rate of New York forests. Of the 8.9 million odt, 75% of this woody biomass would be hardwoods. The majority (57.4%) of the woody biomass is derived from the merchantable category, which includes a wide range of species across the State. The second largest category in terms of 'technically available' woody biomass was the noncommercial species, which made up 32.4% of the total. The total recoverable material (primarily from logging residue) provided about 10.1% of the total.

For Scenario 1, across the State more than 4.8 million odt of woody biomass is available on an annual basis for biofuel or other applications under the conditions outlined in Scenario 1. This material is in addition to current harvesting levels for traditional forest products. This level of harvesting only removes 53.6% of the technically available woody biomass from forests defined as timberland by the USDA FIA program because of the restrictions applied and the use of the Sustainable Yield Model (SYM). Hardwoods make up the majority of the material, accounting for 71.5%. Under the conditions for Scenario 2 and 3, over 6.4 million odt of woody biomass could be available on an annual basis for the production of biofuel or other bioenergy products. This is an increase of 33.5% over the amount of woody biomass under Scenario 1. Estimates of available woody biomass for Scenario 1 are presented in Table E-5 and for Scenario 2 and 3 in Table E-9. Detailed information about estimation of woody biomass feedstock is presented in Appendix E-D.

6. POTENTIAL FEEDSTOCK PRODUCTION FOR SCENARIO 1

For Scenario 1, a number of important assumptions regarding feedstocks are listed below.

On non-forested lands:

- All new feedstock areas will be in perennial vegetation.

- Only warm-season grasses, short-rotation willow, and existing forests are modeled (for other potential feedstocks, see Appendix E-C). Yields of both perennial grasses and willow are modeled based on soil and climate data.

- New feedstocks are grown using good management practices. Management of grasses and willow production is assumed to use inputs required to obtain high yields. However, because these crops are perennials and because good management practices are used, fewer environmental impacts are anticipated from perennials than current annual cropping systems.

- Current agricultural production is maintained (i.e., main agricultural crops and milk), but not necessarily increased. Land currently used for food crops is not converted to production of dedicated bioenergy feedstocks (willow or grasses).

- New fields must be at least five acres in size to facilitate economical management.

- On non-agricultural herbaceous land, an assumed average of about 50% of owners would manage for biomass harvest (more in sparsely populated counties, less in denser populated counties).

- On non-forestland, lands with slopes greater than 15% were not used because steeper slopes are generally unsafe or impractical for standard machinery.

- Federal lands are considered to be unavailable for growing/harvesting non-forest feedstock.

- State protected lands are not considered for growing/harvesting non-forest feedstock.

- Variable land rents are used when estimating production costs for perennial grasses and willow. Higher rents are used for land with greater productivity potential.

On forest land:

- New York forests will stay forests. The scenarios do not convert any forest lands to non-forest lands.
- Only lands that are suitable and available (not reserved in parks, etc.) are harvested.

- Not all owners are assumed to manage for biomass harvest (more in sparsely populated counties, less in densely populated counties).

- Total forest biomass will continue to increase (in other words, total harvest for all purposes will always be less than net current growth).

- Further details on assumptions for forest harvest are presented in Appendix E-D.

Using the assumptions listed above and the methods described below, we estimated the yield from forests, warm-season grasses, and willow throughout New York State. Forest estimates for Scenario 1 are shown in Table E-5. Land available for perennial feedstock in Scenario 1 is summarized in Table E-6. From this, land allocated to willow and grasses is shown in Tables E-7 and E-8 respectively. The total potential feedstock production for each feedstock type is summarized in Figure E-5. For comparison, current forest production and current production of the dominant agricultural crops are also shown in Figure E-5. The projected potential feedstock production for all scenarios is in addition to the current production. All production units are converted to oven-dry tons (odt) to facilitate comparison among different feedstock.

Table E-5. Scenario 1: Potential Wood Chip Production for Bioenergy in New York State.[1]

	Portion of All Live Merchantable Biomass Available	**3% Noncomm. Spp. + 3% Remaining All Live Biomass**	**Total Recoverable Material Not Used**	**Total**
	------------ *oven-dry tons per year* ------------			
Hardwoods	1,772,955	1,255,646	409,130	**3,437,731**
Softwoods	836,196	376,139	159,460	**1,371,796**
TOTAL	**2,609,151**	**1,631,786**	**568,590**	**4,809,526**

[1] See text for explanation of different categories of potentially available wood.

Table E-6. Scenario 1: Sources of Available Land for New Herbaceous and Short-Rotation Willow Feedstock Production in New York State.

Scenario:	**1**
Land Type	**Land Area Suitable and Available**
	acres
Cropland (idle and fallow)	0
Cropland (due to increased crop yield)	0
Cropland (due to increased milk yield per cow)	0
Hayland (due to increased milk yield per cow)	126,962
Miscellaneous rural land (not on farms, not used for horses)	481,973
Miscellaneous rural land in shrub/scrub (not used for horses)	372,637
TOTAL	**981,572**

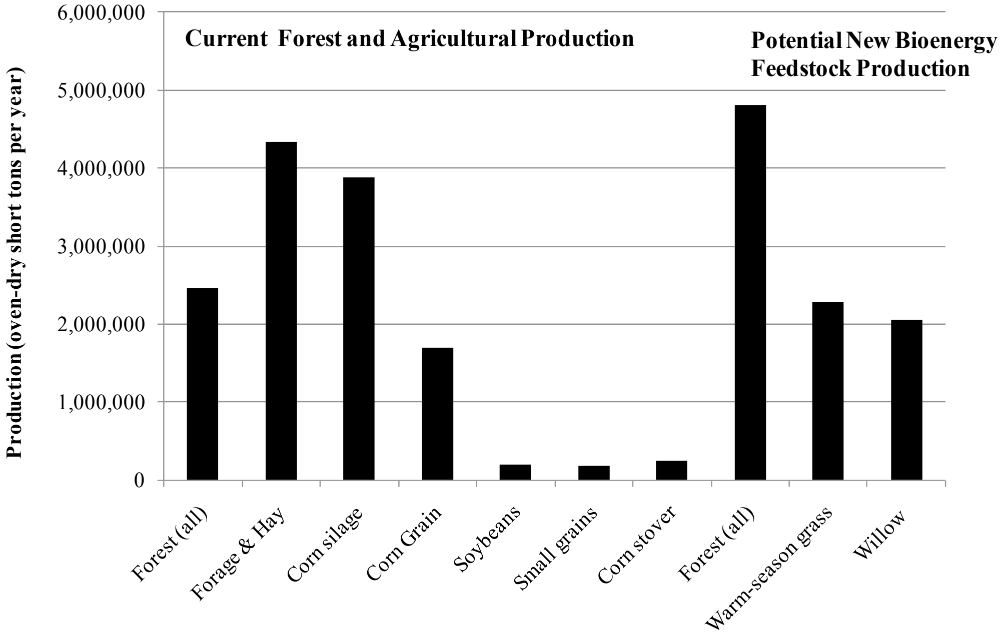
Table E-7. Scenario 1: Potential Short-Rotation Willow Feedstock Production in New York State.

Land Type	Potential Area	Yield	Production (wet weight)	Moisture Content	Production (dry weight)	Average Farmgate Cost
	acres	*wet ton/ac*	*wet tons*	*%MC*	*ODT*	*$/ODT*
Cropland (idle, fallow, or available due to increased crop and milk yield)	0	0.0	0	45.0%	0	$0.00
Hayland (increased milk yield/cow)	25,392	8.8	223,502	45.0%	122,926	$44.00
Miscellaneous rural land (not on farms, not used for horses)	192,789	8.9	1,711,992	45.0%	941,596	$43.63
Miscellaneous rural land in shrub/scrub (not used for horses)	223,582	8.1	1,808,299	45.0%	994,564	$46.25
TOTAL	**441,764**		**3,743,793**		**2,059,086**	

Table E-8. Scenario 1: Potential Warm-Season Grass Feedstock Production in New York State.

Land Type	Potential Area	Yield	Production (wet weight)	Moisture Content	Production (dry weight)	Average Farmgate Cost
	acres	*wet ton/ac*	*wet tons*	*%MC*	*ODT*	*$/ODT*
Cropland (idle, fallow, or available due to increased crop and milk yield)	0	0.0	0	13.0%	0	$0.00
Hayland (increased milk yield/cow)	101,570	5.0	502,828	13.0%	437,460	$75.95
Miscellaneous rural land (not on farms, not used for horses)	289,184	5.0	1,444,342	13.0%	1,256,578	$75.82
Miscellaneous rural land in shrub/scrub (not used for horses)	149,055	4.5	678,041	13.0%	589,896	$77.59
TOTAL	**539,809**		**2,625,211**		**2,283,934**	

Figure E-5. Current Forest and Agricultural Production and Potential Additional Production of Modeled Bioenergy Feedstocks for Scenario 1.



NOTE: Forest (all) means both hardwood and softwood chips from harvests that follow best management practices.

The largest amount of projected potential biomass for Scenario 1 (See potential new bioenergy feedstock production on the right side of Figure E-5) is produced from forests, including both hardwood and softwood chips. Most of the remainder is almost equally split between warm-season grasses and willow. In general, willow and warm-season grasses have similar yields per acre and could, for the most part, be grown on the same land, based on land-owner preference and available markets. The small difference in total new potential production between these feedstocks is due to slightly more land being used for grasses than for willow. The total of all potential feedstock production for scenario 1 is 9.4 million dry tons per year. The total on non-forest land is 4.5 million tons. Thus, this scenario represents an ambitious increase in total potential feedstock production for the State.

7. POTENTIAL FEEDSTOCK PRODUCTION FOR SCENARIOS 2 and 3

Results for developing estimates of sustainable future feedstock production potential for Scenarios 2 and 3 are presented together because they used the same assumptions for production potential. In contrast to the assumptions listed in Scenario 1 above, in Scenario 2 and 3 agricultural production is maintained at current levels, but land becomes available due to increased crop yield and milk yield per cow. That is, these industries stabilize at 2007 production levels for the 2020-2030 Scenario 2 and 3. Specifically, 27% of cropland and 6% of hay land becomes available in Scenario 2 and 3. Feedstock production potential for Scenarios 2 and 3 is presented for wood chips (Table E-9), willow (Table E-10) and warm-season grasses (Table E-11).

Table E-9. Scenario 2 and 3: Potential Wood Chip Production for Bioenergy in New York State.[1]

	Portion of All Live Merchantable Biomass Available	3% Noncomm. Spp. + 3% Remaining All Live Biomass	Total Recoverable Material Not Used	Total
	oven-dry tons per year			
Hardwoods	2,445,782	1,592,278	663,945	**4,702,005**
Softwoods	1,011,483	462,583	245,333	**1,719,399**
TOTAL	**3,457,265**	**2,054,861**	**909,278**	**6,421,404**

[1] NOTE: Non-commercial species are those not used for traditional wood products

Table E-10. Scenario 2 and 3: Potential Short-Rotation Willow Feedstock Production in New York State.

Land Type	Potential Area	Yield	Production (wet weight)	Moisture Content	Production (dry weight)	Average Farmgate Cost
	acres	*wet ton/ac*	*wet tons*	*%MC*	*ODT*	*$/ODT*
Cropland (idle, fallow, or available due to increased crop and milk yield)	71,522	10.0	712,702	45.0%	391,986	$41.34
Hayland (increased milk yield/cow)	50,785	8.8	447,005	45.0%	245,853	$44.00
Miscellaneous herbaceous land (not on farms, not used for horses)	289,090	8.9	2,567,163	45.0%	1,411,940	$43.63
Shrub/scrub land (not used for horses)	285,187	8.1	2,308,900	45.0%	1,269,895	$46.22
TOTAL	**696,583**		**6,035,769**		**3,319,673**	

Table E-11. Scenario 2 and 3: Potential Warm-Season Grasses Feedstock Production in New York State.

Land Type	Potential Area	Yield	Production (wet weight)	Moisture Content	Production (dry weight)	Average Farmgate Cost
	acres	*wet ton/ac*	*wet tons*	*%MC*	*ODT*	*$/ODT*
Cropland (idle, fallow, or available due to increased crop and milk yield)	643,697	5.6	3,607,676	13.0%	3,138,678	$74.05
Hayland (increased milk yield/cow)	76,177	5.0	377,121	13.0%	328,095	$75.95
Miscellaneous rural land (not on farms, not used for horses)	192,727	5.0	962,585	13.0%	837,449	$75.82
Miscellaneous rural land in shrub/scrub (not used for horses)	71,297	4.6	324,655	13.0%	282,450	$77.57
TOTAL	**983,898**		**5,272,038**		**4,586,673**	

7.1 ANALYSIS OF LAND USE IN SCENARIOS 2 AND 3

For Scenarios 2 and 3, the same procedure was used to develop estimates of available area as described above for Scenario 1. Scenario 1 is summarized in Tables E-6 above and Scenarios 2 and 3 are summarized in Table E-12 below.

Table E-12. Scenario 2 and 3: Current Land Cover and Land Use in New York State, and Potential Area for New Bioenergy Feedstock.

Land Cover Type (from NLCD)[1]	Land Area	Suitable Area (not Federal, slope < 15%, field > 5 acres)	Current Crop, Forage, and Hay Land	Current Equine Land Use	Unavailable due to owner preferences	Available Area (our calculation)
	acres	*acres*	*acres*	*acres*	*acres*	*acres*
Crop Land	2,641,314	2,422,795	1,707,577	0	0	715,219
Pasture, Hay & Grass Land	4,612,554	4,144,010	1,962,620	987,000	585,611	608,779
Shrub & Scrub Land	878,170	704,458	0	0	347,975	356,483
Forest Land	16,702,133	15,775,600	0	0	n/a	n/a
Developed land	2,708,501	0	0	0		0
Barren land	58,608	0	0	0		0
Wetlands	2,453,891	0	0	0		0
Open water	1,017,873	0	0	0		0
Other	6,044	0	0	0		0
TOTAL	**31,079,087**	**23,046,864**	**3,670,197**	**987,000**	**933,586**	**1,680,481**

[1] NLCD is the National Land Cover Database, derived from remote sensing imagery circa 2001.

8. COST OF FEEDSTOCK PRODUCTION

The cost of producing a bioenergy feedstock depends on many factors, including the type of management and the yield. For current commodity crops (corn grain and soybean) we used market prices. For corn stover, we used a published estimate of production cost (Graham et al. 2007), and updated it slightly to reflect agricultural production costs of 2007. For softwood and hardwood production, we developed estimates based on the range of costs currently paid by commercial wood chip consumers. This range is

$40 to $60 per dry short ton. We estimated that roughly equal amounts would be available at each of these prices. These costs represent the fact that much woody biomass harvest will occur simultaneously with harvest of higher-value timber (and that if it were the single product harvested, it would be more costly). Perennials such as switchgrass and willow are not widespread crops in New York State so current prices could not be used to develop production cost estimates. Instead, we developed budgets for feedstock production as described below.

8.1 WARM-SEASON GRASS PRODUCTION COSTS

We developed estimates of warm-season grass production costs (by developing an enterprise budget[8] based on high-intensity hay production). Our goal in developing cost estimates was to be as comprehensive as possible, including the cost of money needed to finance the operation: labor, management activities, land rental, and other costs. We assume that in a mature bioenergy industry, producers must be able to cover their total costs to remain in business over the long term. Thus, the goal of this task was to derive estimates of total production costs for the feedstock. This includes all inputs, labor, land, machinery, and the value of the operator's management. Cost estimates were developed as a function of yield so that we could estimate costs for any yield level. Production costs for all feedstock were estimated through an iterative process. Published enterprise budgets were used as a starting point. These budgets were adapted to reflect conditions in New York State by consulting with crop experts, revising assumptions made about production practices, and using state or region-specific estimates of prices paid by farmers. Key assumptions are listed below.

- **Soil amendments:** Rates for nitrogen (N) application were based on expert judgment of the quantities required for obtaining acceptable yields. Rates for phosphorus (P) and potassium (K) were set to replace the amount removed in crop harvest. A single average lime rate was used for all soils.

- **Pesticides:** Herbicides were included in all budgets. Rates shown represent the current best management practices. No insecticides or fungicides are assumed to be necessary.

- **Farm operations:** Data on custom rates[9] were used to represent the combined costs of fuel, labor, and equipment associated with field operations such as tillage, planting, fertilizer application, herbicide sprays, and crop harvest.

- **Harvest and storage:** Calculations account for the cost of harvesting the crop and transporting it to the roadside. No adjustments were made to account for loss of material in storage and transportation.

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[8] An enterprise budget is a written statement of goals for a crop or livestock production activity. It lists the production goals, product mix, profits and losses, fixed and variable costs, etc.

[9] Average rates charged for custom farming on individual farming operations. Rates can be either a single blanket fee or a separate fee for each operation.

- **Yields:** Costs were calculated for a range of potential yields. Harvest costs vary directly as a function of yield. In addition, fertilizer rates for phosphorus (P) and potassium (K) vary as a function of yield since nutrient removal is assumed to be directly proportional to yield.

- **Establishment costs:** Production of perennial crops requires an operator to incur certain costs at the beginning of the crop's life cycle. These costs are recovered over the life of the stand. The total cost of all operations associated with establishing the feedstock was amortized over the life of the crop stand (10 years for grasses) at an annual interest rate of 8%.

- **Land charge:** The cost of owning or renting land was assumed to vary in proportion to the productivity of the underlying soils. Estimates of the land charge were derived for each estimate of yield as per the base rate used by the New York State Office of Real Property Services and the National Commodity Crop Productivity Index associated with a given yield level.

- **Management charge:** An operator's management expertise was valued at 5% of the expected gross returns. Assumptions made about the price of the feedstock are outlined in the individual budgets.

Unless otherwise noted in the budget tables, data on prices of agricultural inputs were obtained from *Agricultural Prices 2007 Summary* (USDA National Agricultural Statistics Service, 2008). Custom farm operations rates were obtained from *2008 Machinery Custom Rates* (USDA National Agricultural Statistics Service 2008).

8.2 WILLOW PRODUCTION COSTS

Unlike the farm enterprise budget used for grasses above, to estimate costs for willow (we used the Eco-Willow model to estimate production costs over a 22-year stand life).[10] However, in order to make estimates more consistent among feedstocks, we adjusted the estimates from the Eco-Willow model to reflect variable land rent values used for other feedstocks (see above). The estimated cost of short-rotation willow and grasses are shown in Figure E-6.

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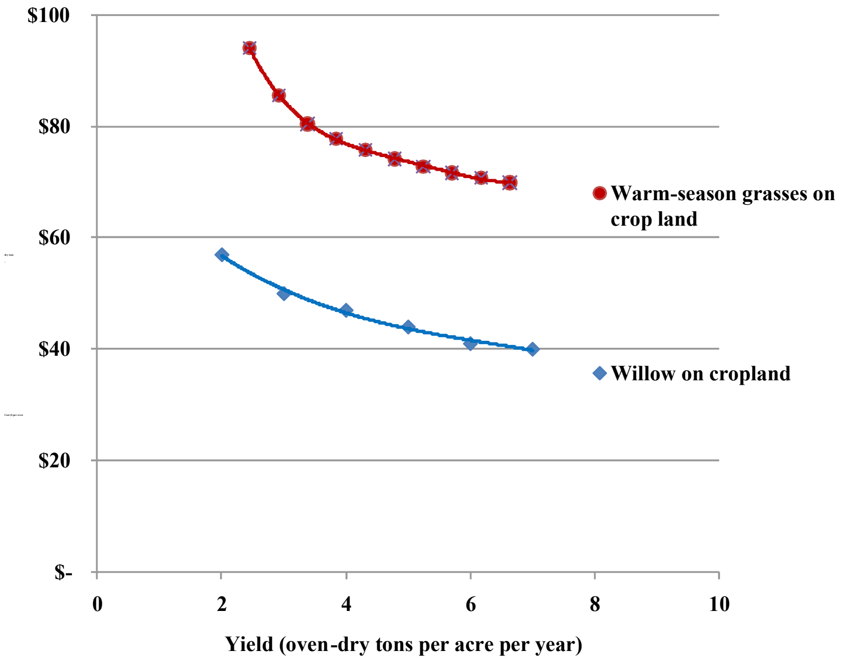
[10] See http://www.esf.edu/willow/download.htm.

Figure E-6. Comparison of Warm-Season Grasses (10-year) and Willow (22-year) Cost Models.



8.3 INTERPRETATION OF COST ESTIMATES

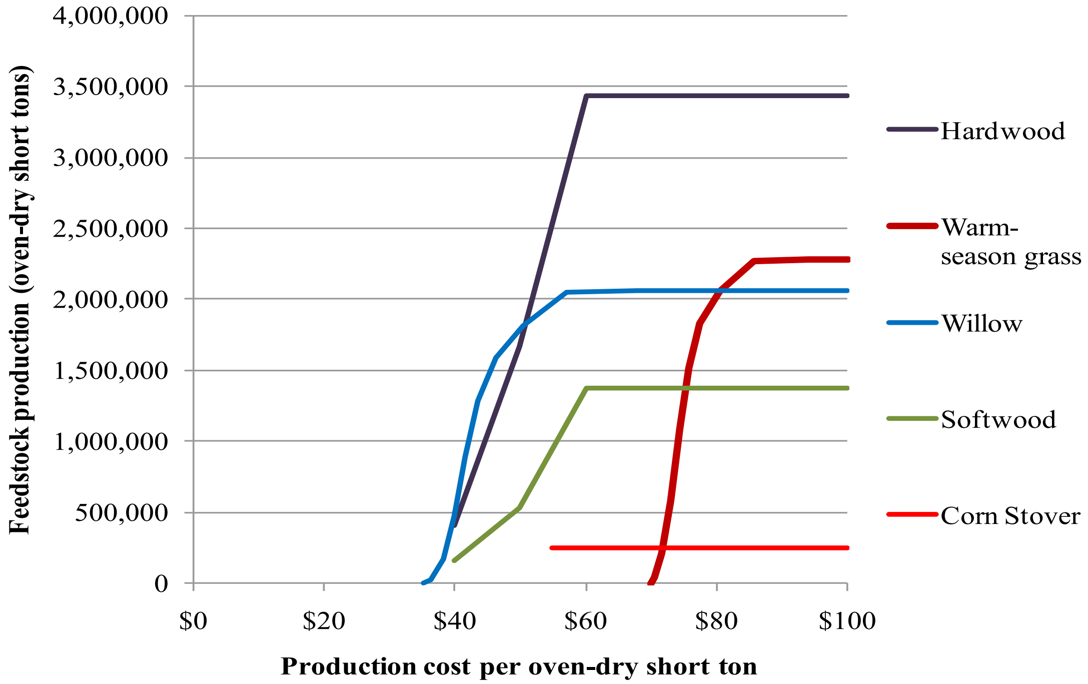
Because warm-season grass and short-rotation willow feedstocks are not produced commercially at the present time, the accuracy of these estimates cannot be readily assessed. Also, the methods for assessing the cost with grasses and willow are not directly comparable (willow model vs. grasses enterprise budget, willow 22-yr amortization vs. grasses 10-yr amortization). The reader should bear in mind that these estimates reflect the current state of knowledge and will change over time with improvements in the scientific understanding and practical application of these crops. Nonetheless, a few generalizations can be made. First, yield can affect the feedstock cost per ton. Second, reducing the number of passes over the field reduces the cost of production of any crop (e.g. willow harvested every three years versus grasses annually). Third, New York State has a surplus of nutrients available in the form of livestock manure, and opportunities may exist to reduce the costs associated with fertilizers through improved farm nutrient management. Use of manure would not only reduce costs, but it could also improve manure management, reducing offsite migration of nutrients that reduce the quality of surface water and ground water. Even so, the practicality of using manure depends on timing of application and harvest management. We developed the budgets using synthetic fertilizer because such fertilizers are easier to manage in enterprise budgets that do not include livestock. For example, hauling wet manure to locations for bioenergy feedstock is energy intensive and a farm that produces manure will likely be using land proximal to the farm for the crops it produces for its livestock.

The estimated prices of willow and warm-season grasses differ not only due to different management requirements, but also because a very different stand life was assumed – 10 years for grasses and 22 years for willow. This difference has a large influence on the estimated annual prices, because there are substantial establishment costs, especially for willow, and amortizing them over a long period such as 22 years reduces the estimated cost per ton of biomass produced. Indeed, this long stand life was selected because shorter stand lives are much less economically viable. However, many landowners may prefer to make a shorter commitment of their land to a feedstock. Thus, it should be kept in mind that the estimated costs for willow depend on this long-term commitment. Another difference between the price estimates for willow and grasses budget included application of P and K (to replace nutrients lost in harvest) whereas the Eco-Willow model did not include application of P and K.

8.4 COST AND PRODUCTION POTENTIAL FOR SCENARIOS 1, 2 AND 3

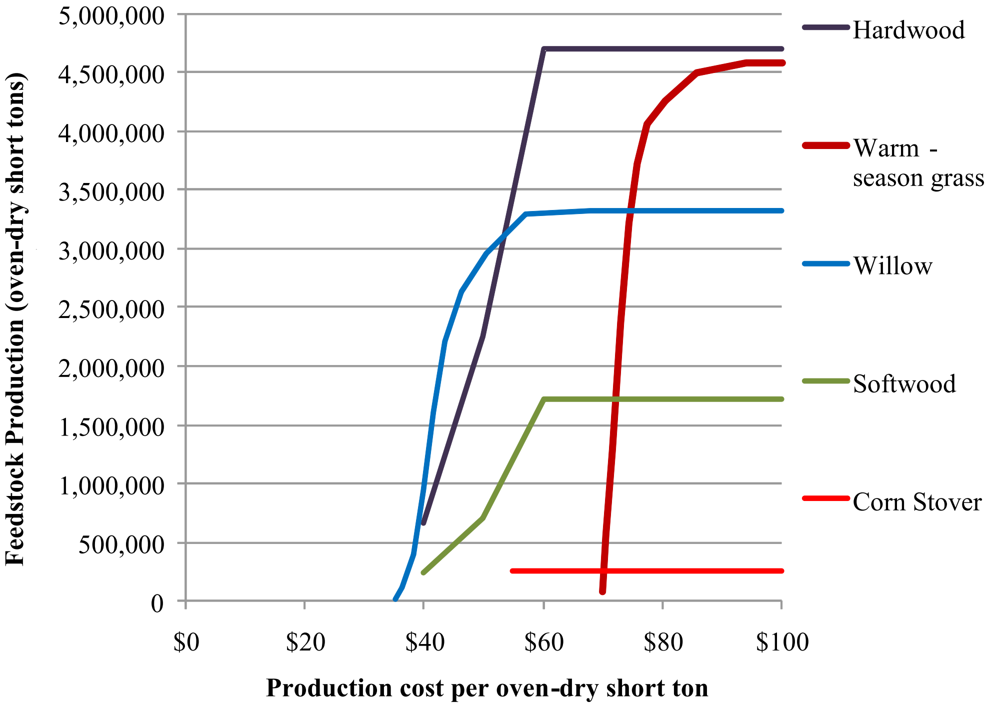
The estimates of feedstock production and cost can be combined to provide "cost curves." The results for Scenario 1 are shown in Figure E-7, and those for Scenarios 2 and 3 are shown in Figure E-8.

Figure E-7. Cost and Potential Production of Bioenergy Feedstocks in New York for Scenario 1.



Note: This figure represents all available feedstocks, but not all feedstocks will be used, depending on assumptions of the price of the biofuel produced.

Figure E-8. Cost and Potential Production of Bioenergy Feedstocks in New York for Scenarios 2 and 3.



As shown in Figures E-7 and E-8, the lowest cost feedstocks are willow, hardwood and softwood from existing forests, and corn stover. The warm-season grasses cost is higher than that of all other feedstocks, but the total production is also high. The large difference in cost between grasses and willow is due partly to the difference in amortization due to stand length (22 years for willow, 10 years for grasses). However, there are other differences in the budgets as well; for example, the grasses budget includes potassium, and phosphorus soil amendments. The cost estimates for hardwoods and softwoods are based on the range of current prices paid for industrial volumes of wood chips, rather than a stand-alone enterprise of just biomass for biofuel harvesting. Thus, they may not reflect the complete long-term costs as was done for grasses and willow.

9. SUMMARY AND DISCUSSION OF POTENTIAL FEEDSTOCK YIELDS AND AREA

The production potential for key feedstocks for the current baseline (corn grain, soybean, and yellow grease) and each future scenario (grasses, willow, soft and hard woodchips) is shown in Table E-13. The land that is suitable and available for potential production of short-rotation willow and warm-season grasses is summarized across scenarios in Table E-14. The area available for harvest of wood from forests is not shown because calculations of available wood were made on a mass basis rather than an area basis (See Section 5.4).

Table E-13. Potential Production of Bionergy Feedstock in New York State: Baseline and Three Future Scenarios at Different Price Points for Biofuel.[1]

Scenario	Hardwood Chips	Softwood Chips	Warm-season grass	Short-Rotation Willow	Corn Stover	Corn Grain	Soybean	Yellow Grease	Total
	------------------------------ *oven-dry tons per year* ---------------------------------							tons per year	
Baseline, Total current production of corn, soybean, & available yellow grease						1,689,614	190,458	75,192	**1,955,264**
Scenario 1, $3 GGE[2]	1,860,870	834,480	0	1,518,530	28,310				**4,242,190**
Scenario 1, $4 GGE	3,437,730	1,371,800	2,276,710	2,059,090	249,940				**9,395,270**
Scenario 1, Maximum	3,437,731	1,371,796	2,283,934	2,059,086	249,943				**9,402,490**
Scenario 2, $3 GGE	4,667,640	1,719,400	4,524,900	3,319,590	249,940				**14,481,470**
Scenario 2, $4 GGE	4,667,640	1,719,400	4,586,640	3,319,590	249,940				**14,543,210**
Scenario 2, Maximum	4,702,005	1,719,399	4,586,673	3,319,673	249,943				**14,577,693**
Scenario 3, $3 GGE	4,667,640	1,719,400	4,585,500	3,319,590	249,940				**14,542,070**
Scenario 3, $4 GGE	4,667,640	1,719,400	4,586,640	3,319,590	249,940				**14,543,210**
Scenario 3, Maximum	4,702,005	1,719,399	4,586,673	3,319,673	249,943				**14,577,693**

[1] For each of the three scenarios, data on the amount of feedstock available at a biofuel price point of $3 and of $4 are presented, along with the maximum amount of feedstock available at the maximum price (see report text for details).

[2] Gallons of gasoline equivalent.

[3] See Appendix I and Appendix L for details on pricing shown in this table

Table E-14. Potential Biomass Feedstock Land Availability for Scenarios 1, 2 and 3 in New York State by Current Land Use Categories.

Land Type	Scenario 1 grasses	Scenario 1 willow	Scenario 1 Total	Scenario 2&3 grasses	Scenario 2&3 willow	Scenario 2&3 Total
	acres	*acres*	*acres*	*acres*	*acres*	*acres*
Cropland (idle, fallow, or available due to increased crop and milk yield)	0	0	0	643,697	71,522	715,219
Hayland (increased milk yield/cow)	101,570	25,392	126,962	76,177	50,785	126,962
Miscellaneous herbaceous land (not on farms, not used for horses)	289,184	192,789	481,973	192,727	289,090	481,817
Shrub/scrub land (not used for horses)	149,055	223,582	372,637	71,297	285,187	356,483
TOTAL	**539,809**	**441,764**	**981,572**	**983,898**	**696,583**	**1,680,481**

There are many important considerations and caveats that should be considered when examining the modeled estimates of potential feedstock production. Many of the key assumptions regarding the availability of land, the intensity of the production systems, and potential yield are discussed above. However, there are other important considerations. One important consideration is that feedstock yields, especially annual crops, will vary greatly among years due to climatic factors, especially summer drought. This variability could pose a real problem for biorefineries that require a certain amount of feedstock each year or month, and presumably have limited capacity to store feedstocks from year to year. This variability will be lower with perennials, particularly for willow and forest trees that are not harvested annually. Reduced variability in yield is another important advantage of woody perennials over annually harvested grasses.

Disease, insects, and other pests can affect all types of vegetation, especially when grown in monocultures with a narrow genetic base over large areas. Little attention has been paid to date on pests and diseases for dedicated feedstocks such as warm-season grasses and willows. As these feedstocks are grown on increasing acreages, such problems will no doubt increase. This consideration highlights the importance of using mixtures of species and genotypes in a single field.

Another important issue is loss of mass or quality during storage. This is an issue for all feedstocks, since they must be delivered to conversion facilities nearly every day of the year, but cannot be harvested throughout the year. Such losses can be minimized if feedstocks were stored under tarps or plastic sheeting, and reduced even further if stored under a roof, but permanent storage structures are expensive and are not included in this assessment.

An additional consideration is competing uses for biomass. We have accounted for competing uses for land by restricting the amount of agricultural land that could be available for feedstock. On non-agricultural land in herbaceous, shrub, or forest cover, we have modeled that half of landowners will choose to use their land to produce biomass feedstocks. However, as various bioenergy industries develop, there will be competition for biomass to produce electricity and heat in addition to biofuels. These issues are discussed in Appendix O and Appendix P.

We have assumed that the social, financial, and technical resources are available for an ambitious expansion of production throughout the State. Appendix M addresses the financial and policy issues, while Appendix J addresses some of the social issues, such as job training. However, the topic of developing essentially new industries and large expansion of existing industries is a complex topic. In brief, we have assumed an optimistic possibility that would require substantial and sustained public and private resources to accomplish.

10. POTENTIAL FEEDSTOCKS FROM URBAN WASTES

A review of this topic was conducted by the Pace Energy and Climate Center, and the results are presented in Appendix E-G. Results for yellow grease are shown in Figure E-13.

11. GREENHOUSE GAS EMISSIONS FROM FEEDSTOCK PRODUCTION

As part of the overall life cycle analysis for key feedstocks, we estimated emissions of the major greenhouse gases (GHG) from "cradle," or source, to the farm gate. Estimates included production of inputs such as herbicides and fertilizer through planting, harvesting, and on-farm transport of harvested biomass to the roadside. Agricultural feedstock included corn grain, corn stover, soybean, warm season grasses such as switchgrass, and short rotation willow. Forest feedstock included chips from mixed hardwood species, and chips from mixed softwood species.

11.1 METHODS USED FOR CALCULATING GREENHOUSE GAS EMISSIONS OF NEW YORK FEEDSTOCKS

The predominant GHGs produced in agriculture and forestry include carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). These gases have different global warming potentials (GWP) so we calculated their CO_2 equivalent values using the Intergovernmental Panel on Climate Change (IPCC) SAR100[11] values: 1, 21, 310 for CO_2, CH_4, and N_2O, respectively. Data for calculations were derived from peer-reviewed journal articles, Cooperative Extension publications, existing models, particularly GREET (version 1.8c.0, see literature cited), and government agency publications. Key peer-reviewed journal articles included the following: Adler et al. 2007, Stehfest et al. 2006, West & Marland 2002. For forest feedstock, data on harvest machinery were derived primarily from the Consortium for Research on Renewable Industrial Materials (CORRIM, see literature cited).

11.1.1 Calculating GHG from Agricultural Feedstock Including Short Rotation Willow

Production of field inputs (nitrogen, phosphate, potassium, lime, and herbicide) and embodied energy in equipment were all derived from GREET. The embodied energy in the machinery was taken either directly from the GREET model or extrapolated from GREET on a weight basis relative to other equipment as per equipment specifications from manufacturers. Fuel use was taken from either GREET or CORRIM for specific operations, or an average of similar equipment activities from journal articles or Cooperative Extension publications deemed most relevant to New York State. Fuel emission factors were taken from GREET. Only off-road diesel, propane, and gasoline fuels were included.

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[11] The GWPs are for a 100-year time horizon and are from the Intergovernmental Panel on Climate Change (IPCC) Second Assessment Report (SAR).

Synthetic nitrogen fertilizer use was assumed to be in the form of urea for all feedstocks because it was the cheapest source of N at the time of this study and because ammonium nitrate is difficult to obtain due to security concerns. Urea illustrates an important concept of life cycle accounting. Urea has a production credit in GREET and a corresponding emission factor according to IPCC; urea absorbs CO_2 during synthetic production and releases this same CO_2 when applied to agricultural fields. However, we assigned neither a credit to the production, nor an emission factor to the farm field because the length of time that CO_2 is sequestered between these activities is too short to be relevant for life cycle analysis.

Manure is an important fertilizer in New York State as dairy is the dominant agricultural activity. While the amount of macronutrients (N, P, and K) in manure is significant, we assumed that all manure was applied to fields growing silage or hay crops and would not generally be used for bioenergy feedstock production. Thus all fertilizer applied to feedstock was either synthetic or mined. Use of only synthetic fertilizer also means that there were no inputs of organic matter to fields where feedstocks were produced, except for residues not harvested.

For nitrous oxide, direct field emissions were based on a statistical model from the scientific literature that was developed based on an extensive database of field measurements from many types of crops, soils, and climatic regions (Stehfest et al. 2006, Bouwman et al. 2002). For New York calculations, we assumed that soil organic matter was always greater than 3% and the pH was between 5.5 and 7.3 (after application of lime as needed). For each crop we made separate estimates for fine, medium, and coarse-textured soils. Then we calculated a weighted average based on geospatial analysis of agricultural soil texture throughout New York State. For forests, we assumed that there was no human-induced emission of N_2O.

In addition to direct emission of N_2O from fields (derived from Stehfest et al. 2006), there is also indirect emission due to subsequent cycling of N after it leaves the field by leaching, volatilization and re-deposition. For most crops, indirect emission of N_2O was estimated based on the rate of N fertilizer applied using methods from IPCC (2006). However, an exception was made for soybean. Soybean is a legume that we estimated receives only 10 pounds of synthetic N fertilizer per acre per year. However, soybean also fixes nitrogen, and a portion of this fixed nitrogen will also eventually be lost from the field due to processes such as decomposition of residue. Therefore, we calculated the ratio of indirect to direct emissions for corn and applied this ratio to our estimate of direct emissions of N_2O for soybean to calculate indirect emissions of N_2O for soybean. Lime field emission of CO_2 was calculated based on methods from IPCC (2006).

11.1.2 Calculating GHG from Land Use Change

Effect of land use change on GHG emission was also calculated. No GHG emission/benefit was assumed for land use change from pasture, hay, or grassland to a perennial bioenergy crop such as perennial grasses or short-rotation willow. However, for a land use change from annual crops to perennial crops, a gradual increase in soil carbon stocks back to the value found under undisturbed (native) conditions was calculated as follows. The first step was to determine how much soil carbon would be found in the native soil, under native (forest) vegetation. Native undisturbed soil carbon stocks were assumed to be 140 Mg C ha^{-1} to a depth of 1 m, based on Woodbury et al. (2007). The next step was to determine how much of this soil carbon had been lost due to tillage. Of this total, 35 Mg C ha^{-1} were assumed to have been lost due to conversion of native forestland to tilled agriculture (Woodbury et al. 2007). The time required to regain the original native soil carbon stocks was assumed to be 33 years, which is approximately three-fold faster than the rate of sequestration under reforestation to a maple-beech-birch forest type (Woodbury et al. 2007). Based on the above factors, carbon sequestration under a perennial crop following an annual crop was estimated to be 1.1 Mg C ha^{-1} yr^{-1}, assuming a linear response, which is a close approximation to the non-linear function used in Woodbury et al. (2007). As no cropland was used to grow perennials in Scenario 1, no benefit from land use change was calculated in Scenario 1. For Scenarios 2 and 3, 69% of the total allocated perennial grassland area (643,697 acres of cropland) and 11% of total allocated perennial willow area (71,522 acres of cropland) was former cropland (see Table E-14 for areas.). As discussed in Section 5.2, a larger percentage of available cropland was assumed to be converted to grasses (as compared to willow) because grasses use only readily available equipment, and grasses are easier to convert back to other crops as willow root systems are difficult to remove. Thus carbon sequestration **averaged** across all lands (cropland + hayland + miscellaneous rural land, Tables E.11 and E.10 respectively) was estimated to be 0.69 Mg C ha^{-1} yr^{-1} for grassland and 0.11 Mg C ha^{-1} yr^{-1} for willow. This C-value was converted to CO_2 equivalents using a factor of 3.6641, for a final estimate of 2.5 Mg CO_2 ha^{-1} yr^{-1} for grassland and 0.4 Mg CO_2 ha^{-1} yr^{-1} for willow, with no amortization period. Thus after 33 years, there will be no further soil carbon sequestration. It should also be noted that if land reverts back to tilled agriculture, the carbon sequestered in the soil due to the prior conversion to perennial vegetation would be lost to the atmosphere over a period of years (i.e., it is lost much more rapidly by tillage than it is sequestered by planting of perennials). Thus, the effect of land use change may be only temporary.

11.1.3 Calculating GHG from Softwood and Hardwood Chips from Mixed-Species Forests

For both hardwood and softwood chip production, management and equipment selections were based predominantly on CORRIM analysis for average conditions in the Northeast and North-Central U.S. Whole tree harvest was analyzed for available material combining residues and merchantable timber potentials. Of course, it is likely that valuable hardwood saw logs would be used for higher value products rather than as a bioenergy feedstock. We assume that harvest would occur simultaneously for saw logs and biomass, with a similar emission of GHG for each, with the additional energy needs in production of wood chips from logs for bioenergy. Forest harvest included hand felling by chainsaw, skidding to roadside, and chipping, but did not include infrastructure costs such as road building as it was assumed that forest harvests would occur where there are already roads available. While there are changes in carbon stocks and sequestration rates throughout the life of a forest stand, we did not give any GHG credit due to harvest. Instead, we assume that in general, forests in New York are on average accumulating carbon as they are generally aggrading (re-growing after clearing and accumulating biomass), and this is their baseline. Thus, we assume that while there are changes in carbon sequestration rates for individual stands, increased harvest for biomass will not change the average carbon accumulation rate of New York forests for many decades, beyond the scope of our analysis.

11.2 GREENHOUSE GAS RESULTS AND DISCUSSION

Overall, for agricultural feedstocks that received nitrogen fertilizer, nitrous oxide emissions from synthetic N application (direct + indirect field emissions of N_2O) was by far the greatest source of greenhouse gases ranging from 65-79% of the total GHG emissions without including land use change. Following synthetic N emissions, lime (production and field CO_2 emissions) and field implements (fuel use plus embodied energy of equipment) were also important. However, for short-rotation willow and warm-season grasses, effects of land use change (conversion of tilled agricultural land to a perennial crop) were similar in magnitude to N_2O emission, but of course were opposite in sign. Results for agricultural feedstock GHG emissions are shown in a per-acre basis in Table E-15 and a per-ton basis in Table E-16.

Table E-15. Cradle to Farmgate Emissions of Greenhouse Gases (g CO_2e/ac) from Production of Corn Grain, Soybean, Warm-Season Grasses, Short-Rotation Willow, and Corn Stover.

NOTE: Units are: (1) CO_2 equivalents per ac (CO_2e/ac) and (2) percentage of sub-total without land use change.

Crop[1]	**Corn Grain**		**Soybean**		**Warm-Season Grasses**		**Short-Rotation Willow**		**Corn Stover**[2]	
N fertilizer (lbs/acre) --->	115		10		68		28		0	
Emission Category										
	g CO2e/ac/y	*%*	*g CO2e/ac/y*	*%*	*g CO2e/ac/y*	*%*	*g CO2e/ac/y*	*%*	*g CO2e/ac/y*	*%*
Equipment (Fuel)	147,630	8%	74,026	5%	32,986	4%	48,166	8%	23,525	58%
Equipment (Embodied Energy)	37,368	2%	32,728	2%	17,025	2%	11,019	2%	17,347	42%
Production of Herbicide, P/K, Seed	98,556	5%	58,542	4%	37,682	5%	7,256	1%	0	
Production of Lime	279,273	15%	279,273	17%	27,927	3%	25,388	4%	0	
Field Lime Emissions	199,622	11%	199,622	12%	19,962	2%	18,147	3%	0	
Production of Synthetic N	61,258	3%	5,327	0%	35,956	4%	15,122	3%	0	
Direct N20 Field Emissions	843,212	45%	786,740	48%	500,945	62%	417,379	70%	0	
Indirect N2O Field Emissions	216,146	11%	201,670	12%	140,965	17%	53,307	9%	0	
Sub-Total without Land Use Change	**1,883,065**	**100%**	**1,637,927**	**100%**	**813,448**	**100%**	**595,785**	**100%**	**40,872**	**100%**
Land Use Change[3]	0	0%	0	0%	-1,019,654	-125%	-160,025	-27%	0	0%
TOTAL	**1,883,065**		**1,637,927**		**-206,206**		**435,760**		**40,872**	

[1] Willow is on a 22 year cycle, warm-season grasses are on a 10 year cycle, corn grain, corn stover, and soybean are on an annual cycle.

[2] It is assumed only 50% of corn acres are harvested for stover, and that on these acres, only 25% of the stover is harvested.

[3] There are no effects of land use change on greenhouse gas emissions in Scenario 1, only in Scenarios 2 and 3, see text for details.

Table E-16. Cradle to Farmgate Emissions of Greenhouse Gases (g CO2e/odt) from Production of Corn Grain, Soybean, Warm-Season Grasses, Short-Rotation Willow, and Corn Stover.

NOTE: Units are: (1) CO_2 equivalents per oven-dry ton (CO_2e/odt) and (2) percentage of sub-total without land use change. Separate analysis is provided for selected price points for Scenario 1, 2 & 3 (e.g. scn1, r150 refers to Scenario 1, run 150). Positive values are emissions to the atmosphere; negative values are removal from the atmosphere.

Crop[1]	**Corn Grain (121 bu/ac)**	**Soybean (40 bu/ac)**	**Grass (scn1,r150)**	**Grass (scn2/3)**	**Willow (scn1,r100)**	**Willow (scn1,r150)**	**Willow (scn2/3)**	**Corn Stover**[2]
N fertilizer (lbs/acre) --->	115	10	68	68	28	28	28	0
Yield (odt/ac)[3]	2.9	1.0	5.6	4.9	5.8	5.6	5.0	0.7
Emission Category								
	------------------------	------------------------	------------------------	*g CO2e/odt*	------------------------	------------------------	------------------------	------------------------
Equipment (Fuel)	51,567	70,906	5,869	6,746	8,248	8,647	9,653	32,870
Equipment (Embodied Energy)	13,053	31,349	3,029	3,482	1,887	1,978	2,208	24,237
Production of Herbicide, P/K, Seed	34,426	56,075	6,705	7,706	1,242	1,303	1,454	0
Production of Lime	97,550	267,503	4,969	5,711	4,347	4,558	5,088	0
Field Lime Emissions	69,728	191,208	3,552	4,082	3,107	3,258	3,637	0
Production of Synthetic N	21,398	5,102	6,398	7,353	2,589	2,715	3,030	0
Direct N20 Field Emissions	294,535	753,582	89,136	102,443	71,469	74,933	83,643	0
Indirect N2O Field Emissions	75,500	193,170	25,083	28,827	9,128	9,570	10,683	0
Sub-Total without Land Use Change	**657,757**	**1,568,895**	**144,742**	**166,349**	**102,018**	**106,963**	**119,396**	**57,107**
Land Use Change[4]	0	0	0	-208,518	0	0	-32,069	0
TOTAL	**657,757**	**1,568,895**	**144,742**	**-42,169**	**102,018**	**106,963**	**87,327**	**57,107**

[1] Willow is on a 22 year cycle, warm-season grasses are on a 10 year cycle, corn grain, corn stover, and soybean are on an annual cycle.

[2] It is assumed only 50% of corn acres are harvested for stover, and that on these acres, only 25% of the stover is harvested.

[3] For corn, soy, stover, hardwood and softwood, the yield is the same for all scenarios. For warm-season grasses and willow, yields differ among different prices points (runs) within each scenario.

[4] There are no effects of land use change on greenhouse gas emissions in Scenario 1, only in Scenarios 2 and 3, see text for details.

Results for forest feedstock are shown on both a per-acre (as averaged across the total New York forest acres) and a per-ton basis in Table E-17. For forests, it was assumed that existing mixed-species forests were harvested and there was no fertilizer or lime applied to this forestland. Therefore, emissions were due only to fuel use and embodied energy in equipment used for harvesting, transport to the roadside, and chipping. While there are changes in carbon stocks and sequestration rates throughout the life of a forest stand, we did not include any GHG credit due to harvest. Instead, we assume that in general, forests in

New York are on average accumulating carbon as they are generally accumulating biomass over time due to prior harvests.

Table E-17. Cradle to Roadside Emissions of Greenhouse Gases from Production of Hardwood and Softwood Chips from Mixed-Species Forests.

NOTE: Units are: (1) CO_2 equivalents per acre for a harvest (not per year) and (2) CO_2 equivalents per oven-dry short ton (CO_2e/odt) and CO_2 equivalents per averaged forest acre (CO_2e/ac).

	Hardwood		**Softwood**	
Yield (odt/ac)	113		67	
Emission Factor				
	g CO2e/ac	*g CO2e/odt*	*g CO2e/ac*	*g CO2e/odt*
Equipment (Fuel)	958,974	8,463	869,131	12,927
Equipment (Embodied Energy)	32,405	286	32,405	482
Production of Herbicide, P/K, Seed	0	0	0	0
Direct N2O Field Emissions	0	0	0	0
Indirect N2O Field Emissions	0	0	0	0
Land Use Change	0	0	0	0
TOTAL	**991,379**	**8,749**	**901,536**	**13,409**

There are several important sources of uncertainty in estimating greenhouse gas emissions from bioenergy feedstock production, including the nitrogen cycle, lime application, and land use change. Given the complex nature of the nitrogen cycle, variability of soil types throughout New York State, and variation in soil moisture status it is difficult to estimate average N_2O emissions for any feedstock receiving N fertilizer. Additionally, there are very few field data on N_2O emission in New York State and the Northeast U.S., and even fewer data that measure a single location throughout most of the year . The Stehfest et al. (2006) model was selected for estimating N_2O emissions because it is a statistical model based on a comprehensive database of field measurements of N_2O emissions. This model reflects actual measurements of N_2O emission under field conditions, and also represents different factors that affect N_2O emission, such as the type of crop, soil texture, and climatic region. Results of N_2O emissions based on Stehfest are somewhat higher than the IPCC global estimates yet fall within the uncertainty range of the IPCC model. However, the roadmap estimates of N_2O emissions are much lower than estimates based on the process-based PNM model specifically cited in New York State (Appendix E-F). Nitrous oxide emissions are higher when soils are wetter. Soils are wetter in regions with frequent precipitation, fine soil texture, and poor drainage. Such conditions are common in many New York soils. The PNM model represents such effects, and thus the results could be relevant to New York conditions and significantly change the overall Roadmap GHG balance unfavorably. However, portions of the PNM model representing the N_2O emission have not yet been peer-reviewed, nor has it been tested with data for New York, because such data are lacking. Thus, it was judged appropriate to include the results from the PNM model in Appendix E-F as a new research result, but not to include them directly in calculating the overall GHG emission from biofuels in this report. However, the PNM results do underscore that there are large uncertainties in estimating N_2O emission. New York soils may be substantially higher than is commonly estimated by other models. From a farm-gate perspective, nitrogen fertilizers, manures, and other sources of N should be managed very carefully to make sure they are applied at the appropriate rate and time to meet crop needs. Adding excess N can be lost to surface waters, ground water, and to the atmosphere. Such careful management can be improved by using an on-line version of the PNM model to obtain recommendations of fertilizer applications based on site-specific data and recent precipitation (Melkonian et al. 2007).[12] Use of the PNM model and other approaches to precision management of nitrogen could increase the sustainability of both crop and biomass feedstock production in New York State.

11.3 DISCUSSION OF LAND USE CHANGE

Increased production of bioenergy feedstock, including annual crops, perennial crops, and short-rotation woody crops, can be achieved by increasing crop yields, increasing the area planted, engaging double cropping systems, or all. If new land is planted to an annual crop such as corn, it may come from land previously planted in an annual or perennial crop, or from some other land use such as forestland. Some changes in land use can cause large emission of greenhouse gases (GHGs) to the atmosphere over a period of years and decades. However, the range of greenhouse gas emissions is extremely variable depending on how the land and biomass are managed. For example, if forests are cleared by burning, a large portion of the carbon in trees will be rapidly emitted to the atmosphere. However, if forests are cleared and the wood is used for bioenergy in place of fossil fuels, GHG emissions will be much lower. In addition to changes in above-ground carbon stocks, land use change can affect soil carbon stocks. If land previously in forest or permanent grassland is tilled, there can be substantial decomposition of carbon and emission of CO_2 from soils over a period of years or decades. Conversely, if land that has been tilled for many years is returned to perennial vegetation such as forest or grassland, soil carbon stocks can increase slowly for many decades as estimated in research results above (Woodbury et al. 2007).

Land use change effects are called “direct” if they are caused by conversion of land from another use to feedstock production, such as converting grassland (pasture, hay, or conservation reserve plan [CRP] land) to bioenergy crop production. Effects that cause changes in land use elsewhere have been termed “indirect.” For example, there has been discussion of whether use of corn grain for biofuel production in the U.S. might cause corn to be planted on previous forestland (thus releasing the carbon in that forest to

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[12] See also http://adapt-n.eas.cornell.edu.

grow the demand for corn) in other parts of the world to meet the global demand for corn grain for food and feed uses. The term "indirect" land use change usually refers to changes in more than one country. However, in a New York context, an indirect land use change might be a change in another U.S. state caused by changes within New York State. The issue of how land use change may affect the GHG balance of bioenergy pathways has received a great deal of attention in scientific literature during recent years. Most of the controversy is about the indirect effects rather than the direct effects. Quantifying indirect effects requires modeling the global food, feed, and fiber production system because one must estimate how changes in, for example, use of cropland in the U.S. affects land use change in another country such as Brazil. While clearly such effects are possible and significant in scale, it is very difficult to quantify the degree to which land use change in one country causes specific changes in land use in another country because there are multiple causes of land use change (Liska and Perrin 2009).

In our analysis, the direct effects of land use change on soil carbon stocks were quantified. Such quantification must be done carefully because the effect of land use change can be very large, and it can be a major portion of the total emission of GHGs over the life cycle of a biofuel. For policy and management purposes, it is important to consider that soil carbon sequestration may be temporary. The results presented in this report indicate that substantial amounts of carbon can be stored with a change from annual cropping to perennial vegetation. However, if this land reverts from perennial vegetation to annual cropping, most or all of this recently stored soil carbon would again be lost to the atmosphere, negatively affecting the overall GHG budget. Additionally, after a change from annual to perennial vegetation, soil carbon will be stored during subsequent years, but eventually a new steady-state will be reached and soil carbon will not increase further.

The effect of potential indirect land use change was not quantified. Instead the feedstock assumptions for Scenarios 1, 2 and 3 were structured to avoid indirect land use change. Specifically, in all three scenarios, current production levels of main agricultural products were maintained even as production of feedstock for biofuels increased. By maintaining current levels of agricultural production, the need to use new additional land outside New York State to meet the State's current needs was avoided. However, it should be noted that in recent decades, New York State has not always produced enough grain to meet the needs of livestock in the State, not to mention the food needs of the people of the State.[13] Also, the current nameplate capacity ("baseline") of biofuel production used in the Roadmap analysis includes two facilities that produce substantial amounts of ethanol from corn grain. If both of these plants operate at nameplate capacity, they would use the equivalent of approximately 75% of the corn grain grown in the State. While the DDGS from this use of corn grain could still meet a portion of livestock's nutritional needs, corn grain would need to be imported into New York to meet the food, feed, and feedstock requirements at this level of ethanol production. Allocating the effect of such choices among these uses is important, but is not an easy analytical task. In summary, current and planned use of corn grain for ethanol production in New

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[13] Population growth was not modeled in the Roadmap.

York State will require importing substantial amounts of corn grain from outside New York. However, the three scenarios developed for advanced biofuel production are designed to avoid adding to such imports, at least for maintaining current agricultural production levels. If greater amounts of food or feed are desired due to human population increases or changes in diet, additional land could of course be required to meet those needs either from within New York State or outside it.

12. RESEARCH NEEDS

Further research on key topics is required to improve understanding of the strengths, weaknesses, opportunities, and threats posed by bioenergy development. Key topics are highlighted below.

Sustainability:

- Advance combined field research and modeling of greenhouse gas emissions from feedstock production, including nitrous oxide emissions from fields and soil carbon sequestration in soil.
- Advance combined field research and modeling of environmental impacts of bioenergy feedstock production over large areas, including the potential for offsite migration of nutrients such as nitrogen.
- Improve understanding of the potential for direct and indirect land use change with different bioenergy development scenarios.
- Investigate large-scale production impacts, such as pests, for dedicated feedstock crops.
- Investigate effects of large-scale biomass harvest from existing forests on species diversity.
- Create a participatory process and iteratively review sustainability criteria and performance standards for adaptive management of biomass resources.
- Create an adaptive management program that iteratively monitors each feedstock and its overall system life cycle for financial, social, and environmental costs and benefits to guide incentives for the most sustainable feedstock production.
- Investigate effect of increased truck traffic on local, state, and interstate transportation networks.
- Investigate effect of increased truck traffic on quality of life in rural areas.
- Assess trends in land development projects (housing/business) for competition of land resources identified in this study.
- Assess environmental impacts from overall system energy use and environmental impact across local and global scales so the positive and negative externalities of local sourcing can be compared to the externalities of outsourcing fuel resources.

Feedstock Development:

- Advance combined feedstock breeding and agronomic practices and modeling, including the use of mixtures of different species in the same field. Expand research trials of different feedstocks across soil type and climate in the State.
- Compare different feedstocks to identify particular strengths and weaknesses in ecological impact, social acceptance and benefit, and end-use conversion efficiency.
- Quantify costs of different harvesting techniques of biomass from existing forests.
- Quantify opportunities for multiple services from a single production system, such as feed and feedstock from grasses or high-value wood products, biomass, and wildlife habitat from existing forests.
- Assess landowner preference for producing different types of feedstock using different production systems as well as length of leasing to a feedstock production management entity.
- Improve feedstock logistics, including practical methods for biomass storage, densification, and reduced transportation costs.
- Assess the capacity of the logging industry infrastructure to meet the potential harvest rates identified in this Roadmap.
- Improve sustainable yield management models and cost curves for each feedstock.

Conversion Efficiency:

- Create improved data and system analysis modeling of the entire production chain for different types of feedstock and conversion technologies.
- Create improved data and modeling of the trade-offs in using different types of biomass to produce different types of bioenergy, including biopower, biofuels, and bioheat.

Policy and Management:

- Assess the trade-offs in using biomass for different types of bioenergy, including electric power, heat, combined heat and power, and liquid transportation fuels.
- Identify policies that inhibit and/or encourage adoption of biomass production from agricultural land, including agricultural tax benefits, ability to use pesticides on non-food products, and local zoning laws.
- Develop best management practices for sustainable biomass production and harvest for annual feedstocks, perennial feedstocks such as willow and grasses, and existing forest feedstocks that include but are not limited to, species selection, pest management, soil nutrient removal, and biodiversity.
- Investigate how town and county zoning, laws, and planning efforts will interact with state-level bioenergy and climate change mitigation goals.

- Investigate internalized versus externalized costs (financial, infrastructural, and environmental) between trucking, train, and barge, and identify policies to improve biomass transport systems.
- Determine if third-party verification of practices is the best approach to ensure sustainable practices or identify other methods of oversight.
- Examine the whole supply chain from infrastructure to policy to identify roadblocks and disincentives that limit or inhibit adoption, as well as identifying sustainability challenges.
- Identify ways to avoid conflicts and enhance synergy for multiple environmental programs and incentives such as renewable energy credits, carbon credits, nutrient trading credits, and land-use change issues. Account for issues of permanence and leakage.

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APPENDIX E-A. DETAILED DESCRIPTION OF GRASS AND WILLOW FEEDSTOCK YIELD MODELING

By Peter Woodbury, Department of Crop and Soil Sciences, Cornell University.

Corn Yield

This section provides additional information on the equations used for modeling yield of various feedstocks. The main section of the report describes the overall approach to developing a regression model of corn yield based on soil characteristics as represented by the National Commodity Crop Productivity Index (NCCPI) and historical yield data from throughout the USA. The resulting regression equation explained 60.4% of the variance and is shown in Equation A.

Equation A. Grain yield in 2002 (bu/ac) = (50.5 + 119*NCCPI)

Where: NCCPI = average of the NCCPI value for corn

In the Northeastern USA, corn yields have been increasing over time. To account for this trend, we performed a linear regression of corn yield for individual states from 1989 to 2008. Results for New York State are shown in Equation B. This equation explained 62% of the variance in yield for the period. Note that units of short tons (= 2000 lb) per acre were used for consistency with other types of biomass production (a bushel of corn weighs 56 lbs). Based on this equation, average yield increases each year by 1.87 bu/ac or 0.053 t/ac.

Equation B. Corn grain yield (bu/ac) =

1.877* year - 3641

Where: Year is 4-digit year after 1989 (example: 2007).

In Equation A, corn yield was estimated based on average yields from 1998 to 2007, thus it represents the year 2002. To make a prediction of corn yield for years subsequent to 2002, yield should be increased by 1.257 bu/ac/yr based on Equation B. Equation C shows the predicted yield for year 2007 accounting for this trend in yield.

Equation C. Corn grain yield in 2007 (t/ac) = (50.5 + 119*NCCPI+1.275*5)*0.028

Where: Short tons per bushel = 0.028

Annual yield increase (bu/ac) = 1.27500

Years after 2002 = 5

Switchgrass Yield

In addition to corn, we developed an equation to predict the yield of warm-season perennial grasses such as switchgrass. There are only a few data from field trials of switchgrass available for the Northeastern US, and our exploratory analysis did not find any significant relationship between NCCPI and switchgrass yield, due to the large variation in yield among sites and years. Based on switchgrass yield data from other locations on marginal lands (for example, Schmer et al. 2008, Perrin et al. 2008), unpublished data from new yield trials in New York State (Dr. Hilary Mayton, pers. comm.), we make the assumption that in coming decades, switchgrass yields on many soils in the Northeastern USA will be similar to the aboveground yields of corn plants. The result is shown in Equation D.

Equation D. Yield (ODT/ac) = (50.5 + 119*NCCPI+1.275*5)*0.028*2*0.845*0.825

Where: Years after 2002 = 5

Adjustment from 15.5% moisture to oven-dry = 0.845

Adjustment for years 1 to 3 (10-yr stand life)= 0.8250

Willow Yield Modeling

Many experiments have been conducted at a number of sites in New York State primarily by researchers at the State University of New York College of Environmental Science and Forestry (SUNY-ESF). Dr. Tim Volk has provided many of these yield data, and together we have developed a database of many of these yield data, along with management and site information. An overview of these data for multiple experiments on multiple clones is shown in Figure E-A.1. The Lafayette site has much lower yields than other sites, apparently due to management challenges, and is not representative of expected yields under best management practices. For the other three sites, average yields across all harvests and clones ranged from 11.2 dry Mg/ha/yr to 14.6 dry Mg/ha/yr, assuming a 3-year harvest cycle. Most of these data are for the first harvest, and yields for subsequent rotations are expected to be higher. For one site (Canestota), yields from the second harvest cycle were 19.4 % greater than those of the first harvest.

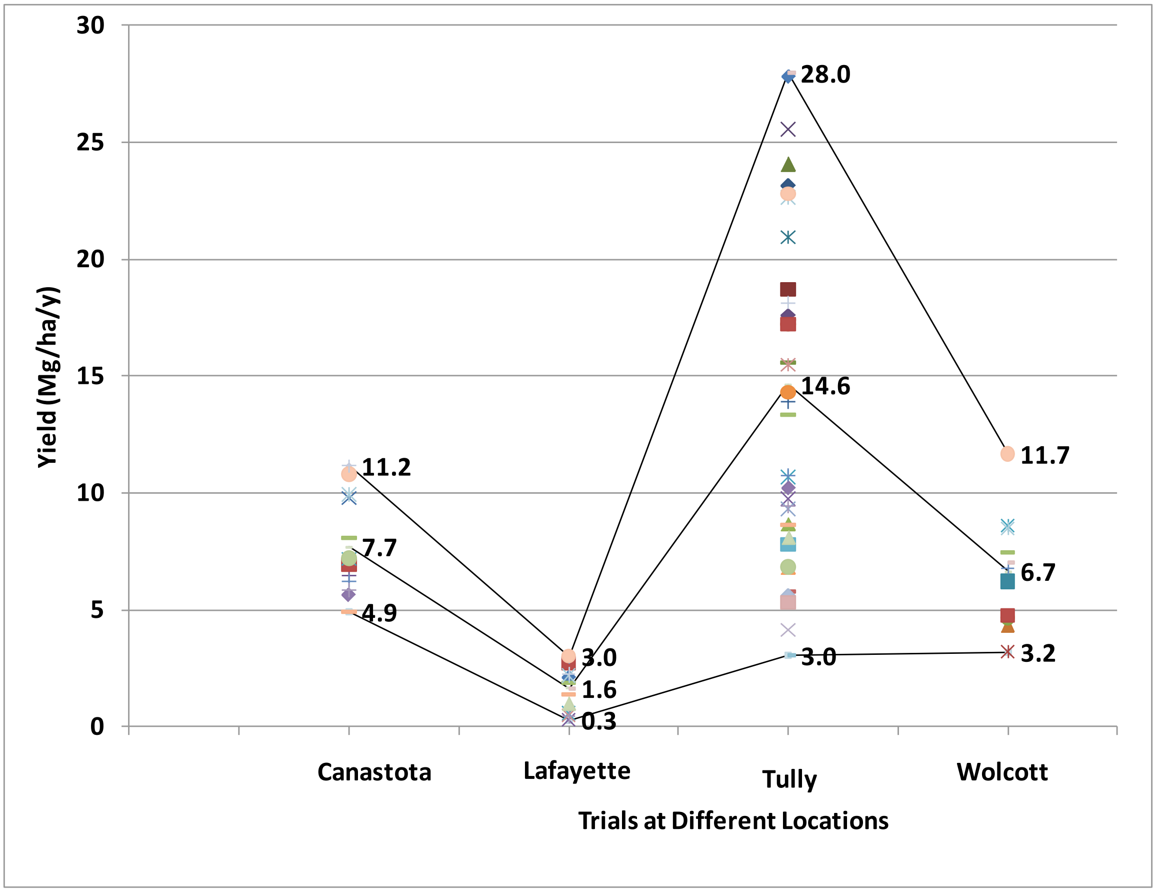

Figure E-A-1. Summary of estimated annual yield of short-rotation willow in New York State for multiple clones and multiple experiments at each site. Annual yields were calculated assuming a 3-year harvest cycle.

Despite the availability of these data from field experiments, it is still challenging to estimate potential yields throughout New York State. Additionally, it is challenging to estimate the potential increases in yield that can be achieved in coming decades with improved genetic material and improved management techniques. To account for differences in soil and climatic conditions throughout New York State, we are using an integrated measure of soil and climate conditions called the National Commodity Crop Productivity Index (NCCPI). This index is under development by the NRCS and is targeted toward agricultural crops. However, it integrates many aspects of soil and climate that are also important for short-rotation willow production. Figure E-A-2 presents yield data from New York State and adjacent states for a single clone (SV1), including the data shown in Figure E-A-1, with the exception of the Lafayette site. These data have been adjusted for the second and subsequent rotations by increasing the measured yields by 19.4% based on the data from the Canastota site. Figure E-A-2 also shows the predicted willow yield based on the NCCPI. This prediction assumes that (1) there is a linear relationship between NCCPI and potential willow yield, (2) second and subsequent rotations will yield more than the first rotation (by 19%), and (3) improved genetic stock will increase yields over those of SV1.

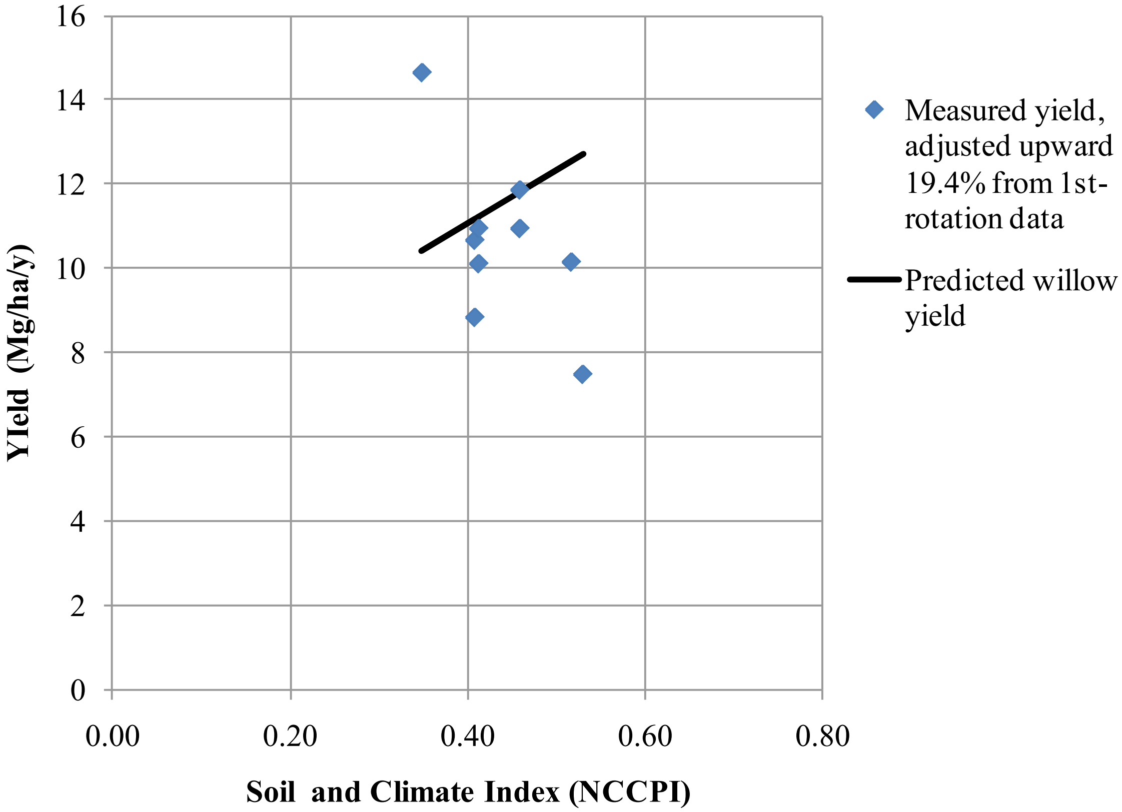

Figure E-A-2. Summary of estimated annual yield of short-rotation willow clone SV1 in New York State in second and subsequent rotations. Annual yields were calculated assuming a 3-year harvest cycle. For all sites except Canestota, first-rotation yields were increased using the ratio of second-rotation yield to first-rotation yield from Canestota (19% increase). Yields for Lafayette are not included due to management problems at that site resulting in lower than expected yields.

The available data do not show a linear trend in yield with increasing values of NCCPI. The NCCPI is designed to integrate important biophysical parameters that affect plant growth. However, the calculation is not based on site specific data, but rather on soils databases that are available for nearly all counties in New York State in digital format (SSURGO). These soils data are the best available for the purpose of predicting plant growth for nearly all soils in New York State. However, they are based on survey data and cannot provide precise data for a specific experimental plot. As discussed we have found that NCCPI is a robust predictor of corn yields throughout most of the United States, explaining over 70% of the variation among counties in average corn yields. Given the smaller data set for willow and the lack of spatial precision in the soils data, it is not surprising that a linear relationship of willow yield and NCCPI is not demonstrated. However, for all but one site, the predicted yield is slightly higher than the measured yield, as expected due to improved genetic material and management practices. Because this model represents biophysical variation in important soils parameters based on data that are available throughout New York State, it is a suitable model for the purposes of the Biofuels Roadmap analysis. This model is shown in Equation E.

Equation E. Yield (ODT/ac) = (50.5 + 119*NCCPI+1.275*5)*0.028*2*0.845*0.9273

Where: Years after 2002 = 5

Adjustment for years 1 to 3 (10-yr stand life) = 0.8250

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APPENDIX E-B. PERENNIAL GRASS PRODUCTION: CURRENT YIELDS AND BEST MANAGEMENT PRACTICES

By Hilary Mayton, Cornell University

Perennial grasses, specifically warm-season grasses, are promising sources of biomass for conversion to liquid fuels, gases, and combustible products. However, in order to be cost effective, growers in New York State must be able to produce high yields of these feedstocks on a per acre basis. A major barrier to the establishment of perennial warm-season grasses in New York State is the limited research and experience with their production. Most of the research conducted on the use of warm-season grasses as energy crops has been done in the Northcentral, South Central, and Southern regions of the U.S. The Cornell Agriculture and Life Sciences Bioenergy Feedstock Project, initiated in 2007, began evaluating perennial grasses for yield and quality through field trials established in multiple locations. Trials established in 2006 and 2007 have provided valuable data for the potential use of these grasses as bioenergy feedstocks in New York State. Switchgrass varieties had greater yields than other warm-season species such as Big Bluestem, Indiangrass, and Eastern Gamagrass in these trials. Third year production yields of switchgrass varieties 'Shawnee', 'Carthage', and 'Kanlow' were 7.0, 6.5, and 7.2 dry short tons/acre (DT/ac) respectively, with 70 lbs nitrogen (N) per acre (applied as ammonium nitrate in late spring). Without N, yields of these cultivars were 4.6, 4.4, and 4.9 DT/ac respectively. Yields obtained in second production year (approximately two-thirds of expected third year stands) trials ranged from 1.8 to 5.0 for switchgrass varieties grown in multiple locations with no fertilizer inputs. These results indicate that yields of 7 DT/ac for switchgrass can be expected when using the best cultivars with good fertility management, although yields may be lower on lower quality sites. Cool season perennial grasses such as Reed Canarygrass, Tall fescue, Wheatgrass, and Rye grass can also be used as bioenergy feedstocks but require more intensive management inputs to attain yields in the range of 4-7 DT/ac. Switchgrass is harvested in a one-cut management system with low fertility inputs whereas cool season grasses typically require 2-4 cuts per season with N applications after each harvest.

Warm-season grasses take longer to establish than cool season grasses and are often at a competitive disadvantage in the cooler climates. Therefore, site selection and preparation are important for successful establishment. If possible, switchgrass should be seeded in fields with low weed pressure. Roundup (glyphosate) can be applied in the fall prior to plowing and seeding. In the spring a second application of Roundup (or generic equivalent) can be made if weeds are a concern. Fields should be plowed and cultipacked before seeding. Switchgrass should be seeded in mid-May with a cutoff around June 15th. Planting at the correct seeding depth for switchgrass is critical for successful establishment. Seed should be planted at ⅛ - ¼ inch into a firm seed bed at a rate of 10 lbs pure live seed/acre with at least 40% germination. It is important to plant the highest quality seed available. A high quality seed lot will have a high % germination, high pure live seed (PLS), and low dormancy. A successful switchgrass stand will have approximately 10-20 plants per square yard or a stand of greater than 40% by the end of the first year.

Fertilizer is not recommended in the seeding year. During the second year fertilizer can be applied according to recommendations from a standard soil test. Mowing once in July at a minimum of 8-10" is required to control weeds in the first year. The field can be mowed off in late fall (after a killing frost) of the establishment year. Starting in the second production year, switchgrass is typically harvested in the fall in a one-cut management system with conventional hay equipment.

No specific warm or cool season perennial grass species has been clearly identified as the most suitable for energy conversion in New York State. Thus, it is important to continue to evaluate a fairly broad range of both warm and cool season grass species and varieties until more information on desirable plant compositional characteristics for energy conversion are known. Research conducted in other parts of the country suggests that mixed stands, either of grasses and legumes or a variety of grasses, may outperform single-species stands, in terms of crop yields, while reducing disease and pest risk at the same time. However, it is not recommended to mix warm-season species and introduced cool season species when developing mixes.

Specific areas of concern identified through these research trials in New York State are the lack of certified commercial seed sources for the warm-season grasses and difficulty encountered with establishment of crops due to intense weed pressure. Additionally, further research is required to identify the most suitable species for somewhat poorly and poorly drained soils.

APPENDIX E-C. ADDITIONAL AGRICULTURAL FEEDSTOCKS WITH POTENTIAL FOR NEW YORK STATE

By Peter Woodbury, Department of Crop and Soil Sciences, Cornell University with others.

Cool-season Grasses From Hilary Mayton, Cornell University

Cool-season grasses are widely grown in New York State for forage and hay production. Because the most commonly grown species are annuals, and because cool-season grasses require substantially more nitrogen than warm-season grasses, we have not emphasized cool-season grasses in the scenarios for advanced biofuels. Nonetheless, they are important crops and could certainly have a place in a "portfolio" of potential feedstocks for New York State. In particular, they may be an important "bridge" between current practices and dedicated bioenergy perennials that require a stand life of 10 or more years to be economically viable. Warm-season grasses such as switchgrass generally do not yield in the first year, while cool-season grasses will. Cool-season grasses such as Timothy, Reed canary grass, Bromegrass, Orchardgrass, or other regionally recognized forages could be planted alone or as part of grass mixtures that compose initial buildup of biomass feedstock. As demand increases, these grasses could be replaced in part by warm-season perennial grasses such as Switchgrass, Big Bluestem, Eastern Gamagrass, and Indiangrass because of their lower requirement for nitrogen and ability to generate an equivalent yield with a single annual harvest. Ultimately, the diversity of grasses will provide real data for both yield and environmental considerations for future cropping decisions. If a strong reliable demand for cellulose develops, then over time landowners may become increasingly likely to adopt a lower intensity short rotation woody crop such as willow that requires a long stand life (22 years) to be economically viable.

Camelina, From work by Joel Hunter, Penn State Cooperative Extension/ Crawford

Camelina is a short season annual crop (85-100 days) that is well adapted to production in the temperate climatic zone and may be able to be double cropped. It performs well under drought stress conditions and may be better suited to low rainfall regions than most other oilseed crops. Camelina is very frost resistant as a seedling and stand losses have not been observed at temperatures as low as 20F. Harvest of early planted camelina will typically take place in July. Unlike many Brassicas, Camelina pods hold their seeds tightly, and seed shattering is not generally a problem. The seeds are ~35% oil. Under dryland conditions in Montana, Camelina is expected to yield 1,800 to 2,000 pounds of seed per acre in areas with 16 to 18 inches of precipitation and 900 to 1,700 pounds per acre with 13 to 15 inches of rainfall. Under irrigation, seed yields of 2,400 pounds per acre have been reported. In Pennsylvania for the 2008 season, Hunter et al. best yields were in the1,000 to 1,500 pounds (20 to 25 bu) per acre range, but none had any commercial fertilizer applied.

Canola, From work by Joel Hunter, Penn State Cooperative Extension/ Crawford

Canola, a type of rapeseed, (spring and winter) is an annual crop that is part of the Brassica family. Research has found that fall varieties yield 30 to 40 percent better than those planted in the spring but improvements to both types continue. Canola is a cool-season crop. It is adapted to long, wet, cool springs. Canola performs best on heavy, deep, fertile loams or clay loams. Spring Canola planting takes place early, well before corn or soybean planting demands, and is also harvested mid-summer reducing late-season harvesting demands and challenges. The winter Canola planting in PA is about the same as late-summer forage seeding or the second half of August (not much later than early September). Canola seedlings are very sensitive to weed competition; therefore, it should be seeded in clean fields at narrow row spacings. It requires 80 to 100 pounds of nitrogen per acre in the spring and 20-30 pounds in the fall. Canola varieties vary about 10 days in maturity. Because Canola shatters easily (1-5 bushels per acre at harvest) most of the canola is expected to be direct combined following a harvest-aid desiccant applied soon after the first pods ripen. Typically, yields average 30 bu/ac or more for spring and 40-50 bu/ac in the fall. Some studies have shown as high as 70 bu/ac. Competition for use includes feed products for livestock consumption and food products for human consumption. Canola meal contains approximately 38% protein.

Sorghum, From work by Steven Kresovich, Cornell University

Among the many potential candidates for bioenergy feedstocks is the annual crop sorghum. Unlike the dwarf grain sorghums grown in the US, the vast majority of sorghum, which comes from Africa, is tall and produces high yields of biomass. Sorghum fixes atmospheric carbon via the highly efficient C_4 metabolic pathway and is known for its high productivity under low fertilizer, water, and pesticide inputs. Studies on dry biomass yield have indicated that sweet and forage sorghums out-produce maize, switchgrass, Reed Canary Grass, Big Bluestem, and alfalfa, especially under low nitrogen input regimes. Though sorghum is a “fine tuned” crop resource for the sub-temperate, semi-arid regions, its broad gene pool has the required diversity for adaptation in many other regions of the U.S. and world. Chinese grain sorghums, for example, are more cold-hardy than US lines and, in a breeding program, these lines could serve as a source of favorable genes for tolerance to low temperatures during the germination and emergent growth phase.

Over the past two years the Kresovich laboratory has conducted a sorghum breeding program with objectives oriented for energy production in Northern latitudes. This work was initially supported by a Northeast Sun Grant Program seed grant. In the summer of 2008, approximately 200 accessions of sorghum were planted in Varna, and Aurora, NY, to evaluate biomass yield and compositional characteristics. Results from these small plot experiments indicated that some lines equaled or exceeded biomass yields of commercial sorghum hybrids (10-15 tons of dry matter per acre). In general, the composition of whole plant biomass was also favorable for biofuel production (high starch and cellulose; low lignin, hemicellulose, and protein). High-yielding lines were increased last year in a winter nursery (Puerto Rico) where ~300 crosses were performed for producing hybrids. These hybrid lines will be evaluated in small plots summer 2009 along with 25 Chinese lines that purportedly have high germination rates and vigorous seedling growth in cold climates. Seed from selected lines and hybrid crosses will, again, be increased during the winter of 2009-2010 for more extensive plantings in the spring of 2010. Our small plot work has confirmed the feasibility of developing high-yielding biomass sorghum inbred lines and hybrids that are well adapted to northern climates. In 2010, the goal is to partner with producers to expand our initial evaluations to encompass larger plots and a broader range of within-State growing environments.

APPENDIX E-D. ASSESSMENT OF AVAILABLE FOREST BIOMASS

By T.A. Volk, P. Castellano, R. Germain, and T. Buchholz, SUNY- ESF, Syracuse, NY

Background

The objective of this analysis was to provide an estimate of the sustainable level of woody biomass that could be harvested from forests in New York on an annual basis. Multiple restrictions and limitations were identified and applied to the available U.S. Forest Service (USFS) Forest Inventory Analysis (FIA) data during the development of these estimates. Due to the scale of these assessments and the nature of the available datasets, site-specific sustainability concerns could not always be incorporated into these estimates. Issues related to site-specific harvesting activities are covered in the discussion of best management practices and forest biomass harvesting guidelines in other sections of this report. During this analysis we applied restrictions at the county level and used a sustainable yield model at the township level to address concerns related to the sustainability when estimating the amount of woody biomass that can be harvested from forests and used for biofuels, bioenergy or bioproducts other than traditional forest products. The main restrictions applied are listed below in Table 1 and are discussed in more detail in the context of the methodology used to develop these estimates.

Table E-D-1. Restrictions applied to address sustainability concerns during the estimate of annual biomass potential from NY forests.

Limitation or Restriction Applied	Issue or Concern Being Addressed
Estimates of available woody biomass are based on the area of timberland[14] in New York not forestland, so forest preserve[15] and other protected areas were not included.	Woody biomass in parks with harvesting restrictions and other protected areas that are not currently accessible for harvesting should not be included
Set the upper limit for harvesting as the net annual growth rate[16] on timberland in each county in New York.	Depleting New York forest resources at a rate faster than they are growing by using a sustained yield approach. Under this restriction New York forest biomass capital within each county is not reduced.

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[14] Timberland is defined by the U.S. Forest Service as forest land producing or capable of producing crops of industrial wood (more than 20 cubic feet per acre per year) and not withdrawn from timber utilization (formerly known as commercial forest land).

[15] The Forest Preserve is defined as the State land within the Adirondack and Catskill Parks afforded constitutional protections that prevent the removal of timber; lands within New York's Forest Preserve exhibit exceptional scenic, recreational, and ecological value. (http://www.dec.ny.gov/lands/5263.html.)

16 Net annual growth: The change, resulting from natural causes, in growing-stock volume during the period between surveys. Components of net growth are in growth plus accretion, minus mortality, minus cull increment, plus cull decrement.

Limiting the proportion of forest residues that can be collected. In this analysis, 35% of the currently unused residues from logging are left on site. In addition, estimates of increased biomass harvested from the 'all live merchantable[17]' class were limited to a four inch top diameter, meaning that all tops and branches from these trees would also be left on the site.	Because of the concerns related to nutrient removals and biodiversity associated with the removal of coarse and fine woody debris during biomass harvesting, limits were set on the proportion of tops and branches that could be removed during harvesting operations. Biomass harvesting guidelines that have been developed in other states recommend that 20 – 33% of residues be left on site (Evans and Perschell 2009).
Restricted removal of dead trees	Mortality was assumed to be left on the site to provide habitat, snags, course woody debris and nutrients on site.
Accounting for wood that is harvested for other forest products.	Current harvesting levels of wood in New York's forest are included in the estimates for a total amount of biomass removed for traditional forest products (veneer logs, sawtimber, pulp, fuelwood, post\poles\pilings, miscellaneous). The combination of harvests of traditional forest products and biomass for biofuels does not exceed the net annual growth in any county.
Use of a sustainable yield management (SYM) model based on Vickery et al. 2009.	This model was applied at the township level using road density data at the township level to address concerns related to site conditions, future demographics, or potential development that might impact long term sustained yield management.
Modification of road density calculations in townships within the Adirondack and Catskill Parks to account for inaccessible areas classified as forest preserve.	Since large areas of the forest preserve have restricted road access and harvesting policies, this was accounted for by removing the land area in the forest preserve in each township before calculating road density, which was the main factor used in the SYM model. This resulted in a higher road density in these townships and a lower estimate of the area where SYM could occur.

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[17] Merchantable biomass: The main stem of all species > 5" d.b.h. between a 1-foot stump height and a 4" top diameter (outside the bark), including rough and rotten culls (same as all live merchantable biomass).

Methods

Estimates of sustainable levels of woody biomass that could be harvested from forests in New York on an annual basis were calculated based on methodologies that had previously been developed and applied to determine amounts of woody biomass available in supply sheds in different regions of New York (Castellano et al. 2009). For this project, county-by-county estimates were developed using the most recent data available from the USFS FIA and Timber Products Output (TPO) Websites. The FIA data used is from inventories conducted in New York from 2002 through 2006. TPO data is from inventories and surveys conducted in 2007.

The estimation procedure used followed two main steps. The first step was to determine the amount of technically available woody biomass from timberland in each county in New York. ‘Technically available’ is the amount of woody biomass that is available and accessible and within the limits of a sustainable yield from the timberland in each county (Castellano et al. 2009). The amount of this woody biomass that will actually be available for biofuels or other applications is strongly influenced by the socioeconomic aspects of growing and harvesting woody biomass. The second part of the process estimated the amount of technically available biomass that is likely to be available to harvest based on a recently developed model of sustainable yield management (Vickery et al. 2009).

Step 1: Determination of Technically Available Woody Biomass

Only woody biomass from timberland was considered for these assessments. Timberland is defined by the USFS as forest land producing or capable of producing crops of industrial wood (more than 20 cubic feet per acre per year) and not withdrawn from timber use. As a result, land where harvesting is prohibited due to regulations or guidelines, primarily forest preserve, was not included in this assessment.

1.1 Portion of Technically Available Merchantable Biomass

The portion of all live merchantable biomass that is available for biofuels was calculated by determining the net annual growth of growing-stock and then subtracting the amount of all biomass that is currently being harvested for traditional forest products in each county using the most recent TPO data.[18] (The result of this process is that the amount of material that is currently harvested plus that portion of all live merchantable biomass that could be removed for biofuels or other applications does not exceed 100% of the net annual growth. The definition of merchantable biomass assumes that the tops (< 4 inches in diameter) and branches are not harvested. Rather than adjust the amount of biomass available for biofuels with a factor to estimate the amount of biomass in tops and branches, we assumed that all this material would be left on site in order to address concerns associated with biomass harvesting, especially nutrient removals from the site, coarse and fine woody debris removal and biodiversity (Evans and Perschel 2009).

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[18] See http://ncrs2.fs.fed.us/4801/fiadb/rpa_tpo/wc_rpa_tpo.ASP

Portion of Technically Available Noncommercial Species. This estimate was compiled by first identifying the amount of standing biomass of the noncommercial[19] trees in each county based on the most recent FIA data. Biomass associated with all trees <5" diameter breast height (dbh) was then removed since this material is not easily harvested and collected. Then, 3% of this standing biomass value was assumed to be available each year for biofuels or other products each year.

Portion of Technically Available Remaining All Live Biomass. This estimate was compiled by first taking the difference between the FIA assessment of the total standing biomass (called all live biomass[20] by FIA) on timberland in the county and all live merchantable biomass by county, which was determined in step 1.1. Next, the amount of sapling biomass (1- 4.9" dbh) was subtracted because this small diameter material will be difficult to collect effectively with current harvesting systems. Then, the amount of biomass associated with noncommercial species ≥ 5" dbh was subtracted because it was estimated in step 1.2 (see below). Three percent of the remaining biomass was assumed to be available each year for biofuels applications.

Portion of Technically Available Recoverable Logging Residue. This estimate was compiled by assuming that 65% of the available residues from current harvesting operations in each county based on the most recent TPO data were collected for biofuels or other applications. Leaving 35% of these residues on the site exceeds the range of current removal values of 20 – 33% recommended in biomass harvesting guidelines (Evans and Perschel 2009). In addition, we have assumed that all the tops and branches from any additional harvesting of merchantable biomass will remain on the site (see section 1.1). The 65% recovery figure has been used in national assessments of the availability of woody biomass (e.g. Perlack et al. 2005).

Portion of Technically Available Recoverable Other Removals. This estimate was compiled by taking 50% (the estimated recoverable portion) of the other removals[21] as reported in the 2007 TPO data by county. Other removals include biomass from land clearing and cultural operations.

Total Technically Available Forest Biomass by County. The total technically available biomass for each county was determined by adding the values from 1.1, 1.2, 1.3, 1.4, and 1.5.

Step 2: Potentially Available Woody Biomass

Potentially Available Forest Biomass Estimates for Scenario 1

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[19] Noncommercial species: Trees species of typically small size, poor form, or inferior quality that normally do not develop into trees suitable for industrial roundwood products.

[22] Other removals: Unused wood volume of trees cut or otherwise killed by cultural operations (e.g. pre-commercial thinnings) or land clearings to non-forest uses. Does not include volume removed from the inventory by reclassification of timberland to productive reserved forest land.

This step accounts for differences in the amount of technically available biomass from timberland and the amount of woody biomass that is likely to be available due to socio-economic and sustainability constraints under current conditions. This is a complex set of factors in New York because over 85% of the timberland is controlled by industrial and nonindustrial private forest land owners in the State and there is an array of different opinions about forest management among them (Munsell and Germain, 2007). We adjusted for these factors based on a sustainable yield management (SYM) model recently developed by Vickery et al. (2009). The model estimates the proportion of the forested area within a township that is expected to be available for sustainable yield management now and into the future. Sustainable yield management was defined as "the ability for an area to be managed in such a manner that would ensure a continuous supply of timber through time" (Vickery et al. 2009). A number of different factors were assessed to determine what currently available parameters could be used to estimate SYM. Road density was found to be the primary variable influencing the likelihood of sustained yield management in a five-county region in central New York, and was the factor used to apply this model for these estimates.

Using townships (by county) as the base study unit, road density was calculated as the length of major roads in miles divided by the township land area in square miles using ArcMap road and civil division datasets that were acquired from the NYS GIS Clearinghouse (http://www.nysgis.state.ny.us/). These datasets are maintained by the NYS Office of Cyber Security and Critical Infrastructure Coordination (CSCIC) and are of the highest quality and accuracy. The area covered by major water bodies in each township was removed to determine the total land area. For the townships that included forest preserve as a major land use, the determination of road density was modified by removing the land area and road mileage in the forest preserve. So the road density in these townships was determined by dividing the total length of major roads by the modified land area (total area of the township – area of the township in the forest preserve).

The calculated road density for each township was then used in the model developed by Vickery et al. (2009) to estimate the likelihood of SYM in that township. This SYM factor for each county was determined by taking a weighted average of the township based on the land area of each township as a proportion of the total land area of the county in which the township is found. The county level SYM factor was applied to the estimated 'technically available' forest biomass calculated in section 1.6 in each county. The resulting forest biomass numbers are the estimates for the amount of woody biomass from timberland in NY that could potentially be available for biofuels or other applications on an annual basis for scenario 1. Scenario 1 is the baseline scenario used for the siting model that was run for other portions of the biofuels roadmap project.

Potentially Available Forest Biomass Estimates for Scenario 2 and 3

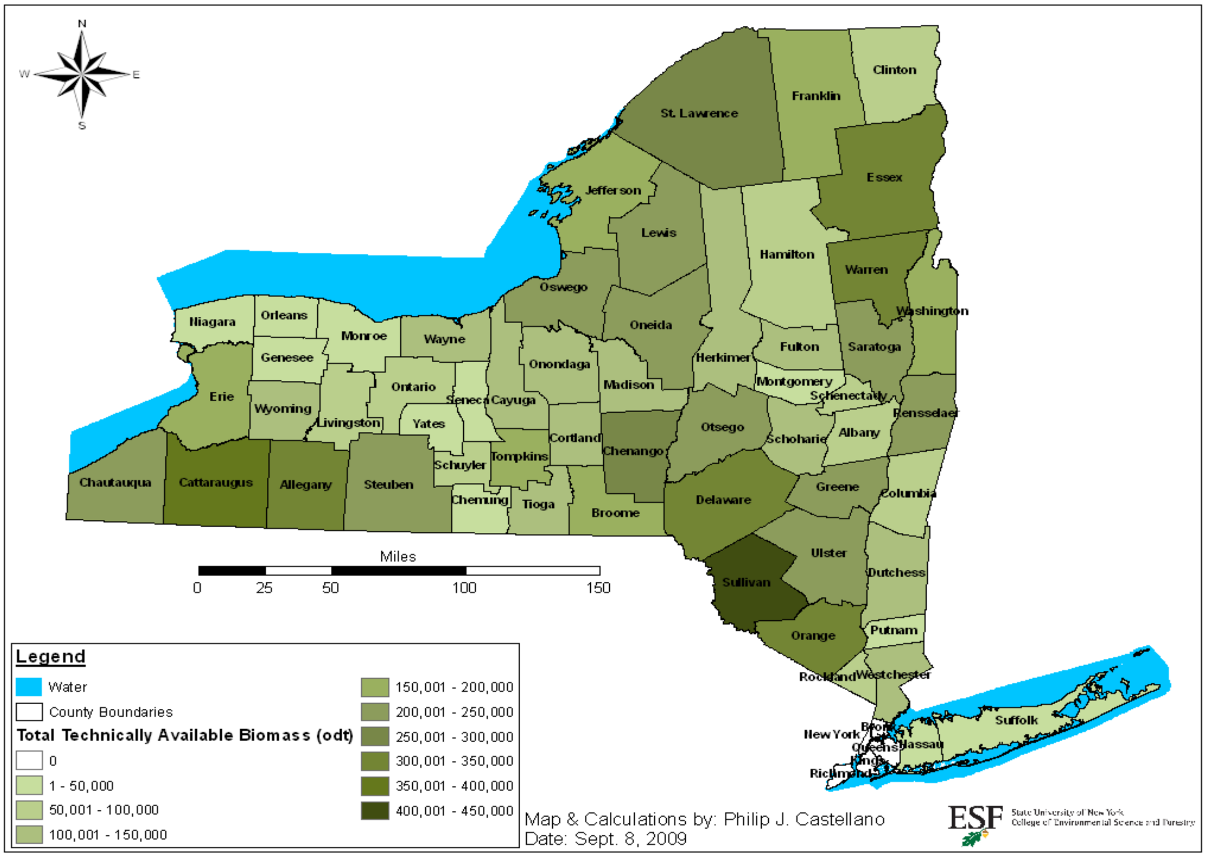
An additional set of forest biomass estimates were made for Scenarios 2 and 3 for the siting model. These estimates were made using the following set of assumptions and steps. First the difference between the technically available biomass (section 1.6) and the potentially available biomass (Step 2.1) was calculated.

We assumed that additional demand for biomass would increase the level of harvesting by creating more market opportunities and increasing the level of interest among landowners. We assumed that 1/3 of this difference for the categories of merchantable biomass, non commercial species and remaining all live biomass would become available for the biofuels or other products. We also assumed that 100% of the recoverable material from current harvesting operations for traditional forest products that is not currently being used would be collected for the biofuels market. These additional materials in each county were then added to the values for Scenario 1 to estimate potentially available woody biomass for Scenarios 2 and 3.

Results

While New York State has 18.5 million acres (18,464,222 acres) of forest land according the USFS, not all of this land base was considered for these assessments. Only 15.8 million acres (15,781,242 acres) of New York's forest land is classified as timberland, which removed all the land that is in federal, State or county parks that is not available for active management because of policies and regulations. Based on the current FIA data, the State-wide net annual growth rate growing stock is 9,551,724 odt (http://www.ncrs2.fs.fed.us/4801/fiadb/fim40/wcfim40.asp). Note that this is not total growth of the forest, because it does not include non-merchantable species, non-merchantable portions of trees and does not include all forests.

The estimates of 'technically available' woody biomass from New York's forests indicates that over 8.9 million oven dry tons (odt) could be harvested each year (Figure 1, Appendix E-D). This is a Statewide average of 0.57 odt/acre of timberland. This amount of harvesting combined with current rates of removal for traditional forest products would not exceed the net annual growth rate of the NY's forests. Of the 8.9 million odt, 75% of this woody biomass would be hardwoods. The majority (57.4%) of the woody biomass is derived from the all live merchantable category, which includes a wide range of species across the State. The second largest category in terms of 'technically available' woody biomass was the noncommercial species, which made up 32.4% of the total. The total recoverable material provided about 10.1% of the total. The vast majority (89%) of the total recoverable material was made up of logging residues that are currently not being harvested



FigureE-D- 1. Technically available woody biomass from timberland in each county in New York.

Amounts of technically available woody biomass varied widely across the counties from 822 odt in Nassau County to 448,601 odt in Sullivan County. Only seven counties in the State had the potential to produce over 300,000 odt per year – Allegany, Cattaraugus, Delaware, Essex, Orange, Sullivan and Warren.

Potentially Available Woody Biomass from Forests for Scenario 1

In order to account for a range of socioeconomic factors that affect the proportion of the technically available forest biomass that is potentially available, the sustainable yield management model developed by Vickery et al. (2009) was applied to all the townships across the State. The model predicts the proportion of land area available for SYM based on the road density in each township. After applying the model and weighting the value in each township based on its land area, the proportion of timberland available for SYM ranged from 0% for five counties in New York to greater than 90% for five other counties (Figure 2). Across the State the average potential for SYM is 49%. The largest number of counties (11) had a sustainable yield management potential of between 40 and 49% (Figure 3).

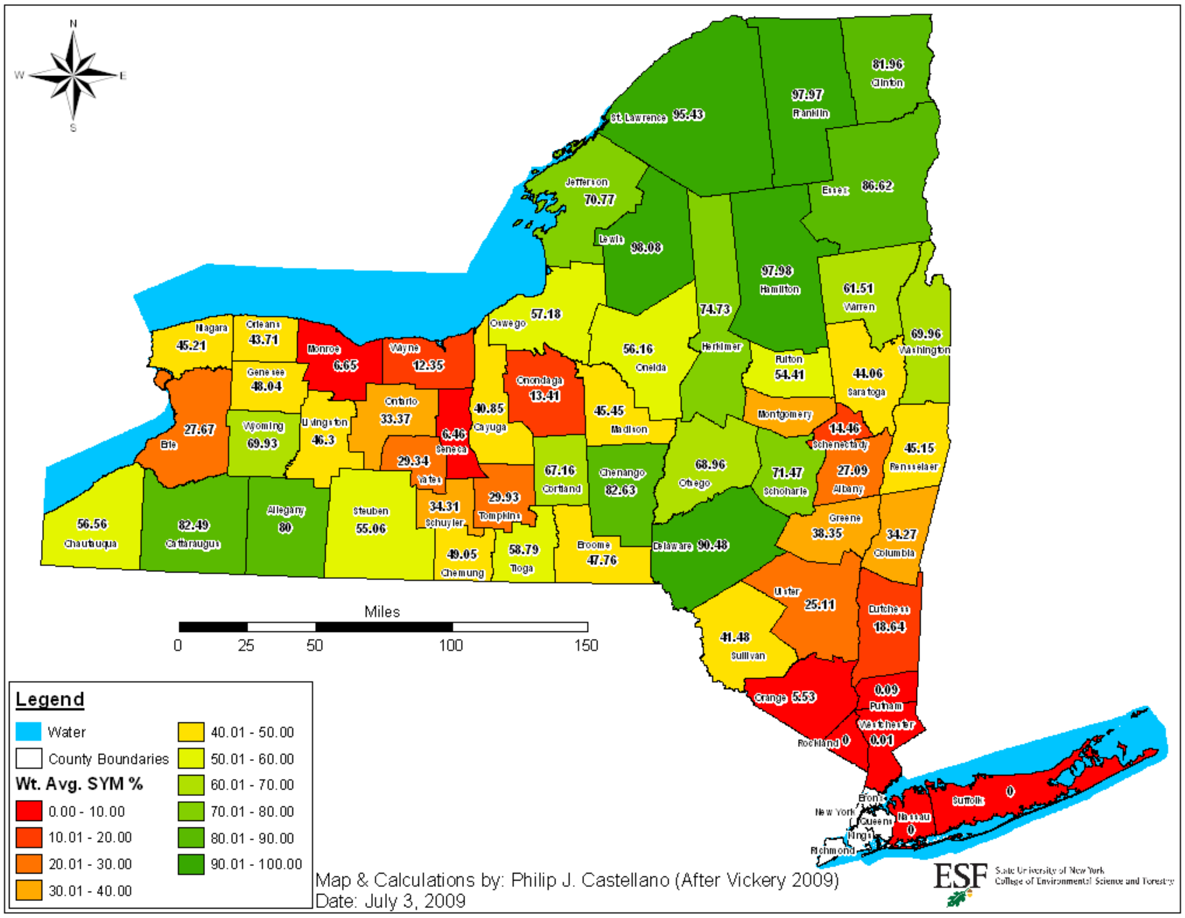


Figure E-D-2. Potential for sustainable yield management in New York State by county based on road density (modified for the land area in the Adirondack Park) using the model developed by Vickery et al. (2009).

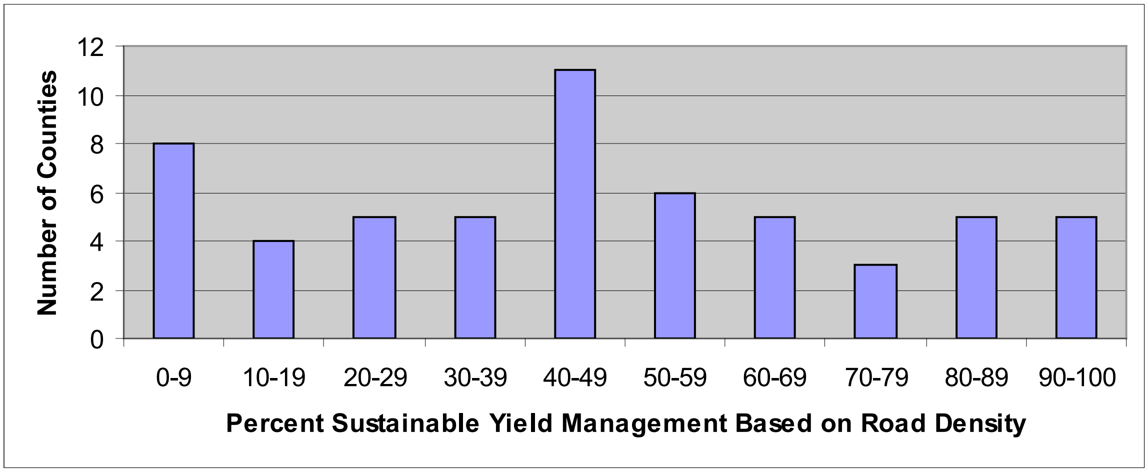


Figure E-D-3. Distribution of counties based on predicted sustainable yield management potential using the model developed by Vickery et al. (2009).

Modifying the road density values for the land area in forest preserve in the Adirondack and Catskill Parks reduced the SYM potential in each county, but the effect varied widely across the 16 counties. The greatest change occurred in Ulster County, which was reduced by 50% (Table 2). For three of the counties (Fulton, Greene, and Warren) the reduction in the SYM percentage was between 24% and 33%. For nine of the counties the change was very small (< 5%).

TableE-D- 2. Changes in sustainable yield management values before and after adjusting road density figures for land in the forest preserve.

	Sustainable Yield Management Potential (%)	
County	Before adjusting for the land area in the forest preserve	After adjusting for the land area in the forest preserve
Clinton	82.8	82.0
Delaware	92.8	90.5
Essex	99.5	86.6
Franklin	98.6	98.0
Fulton	73.1	54.4
Greene	57.3	38.4
Hamilton	99.9	98.0
Herkimer	84.6	74.7
Lewis	98.3	98.1
Oneida	56.6	56.2
Saratoga	46.1	44.1
St. Lawrence	95.9	95.4
Sullivan	45.2	41.5
Ulster	50.5	25.1
Warren	81.0	61.5
Washington	71.5	70.0

Technically available forest biomass figures were modified using the percent sustainable yield management generated for each county to predict the amount of forest biomass that would be potentially available on a county-by-county basis for scenario 1. Across the entire State over 4.8 million odt of woody biomass is available for biofuels or other applications on an annual basis, which is 53.6% of the technically available woody biomass. Hardwoods make up the majority of the material, accounting for 71.5%. The majority (54.2%) of potentially available woody biomass was still in the all-live merchantable category followed by the noncommercial species, which made up 33.9% of the estimate, and the total recoverable material (11.8%).

The application of the sustainable yield model influenced the distribution of potentially available woody biomass across the State. The amount of potentially available woody biomass ranges from 0 odt in Nassau, Rockland, and Suffolk counties to over 300,000 odt in Delaware and Essex counties (Figure 4). There were five other counties (Allegany, Cattaraugus, Chenango, Lewis, and Warren) with the potential to produce over 200,000 odt of woody biomass from forests per year. Twenty-six counties had the potential to produce less than 50,000 odt per year.

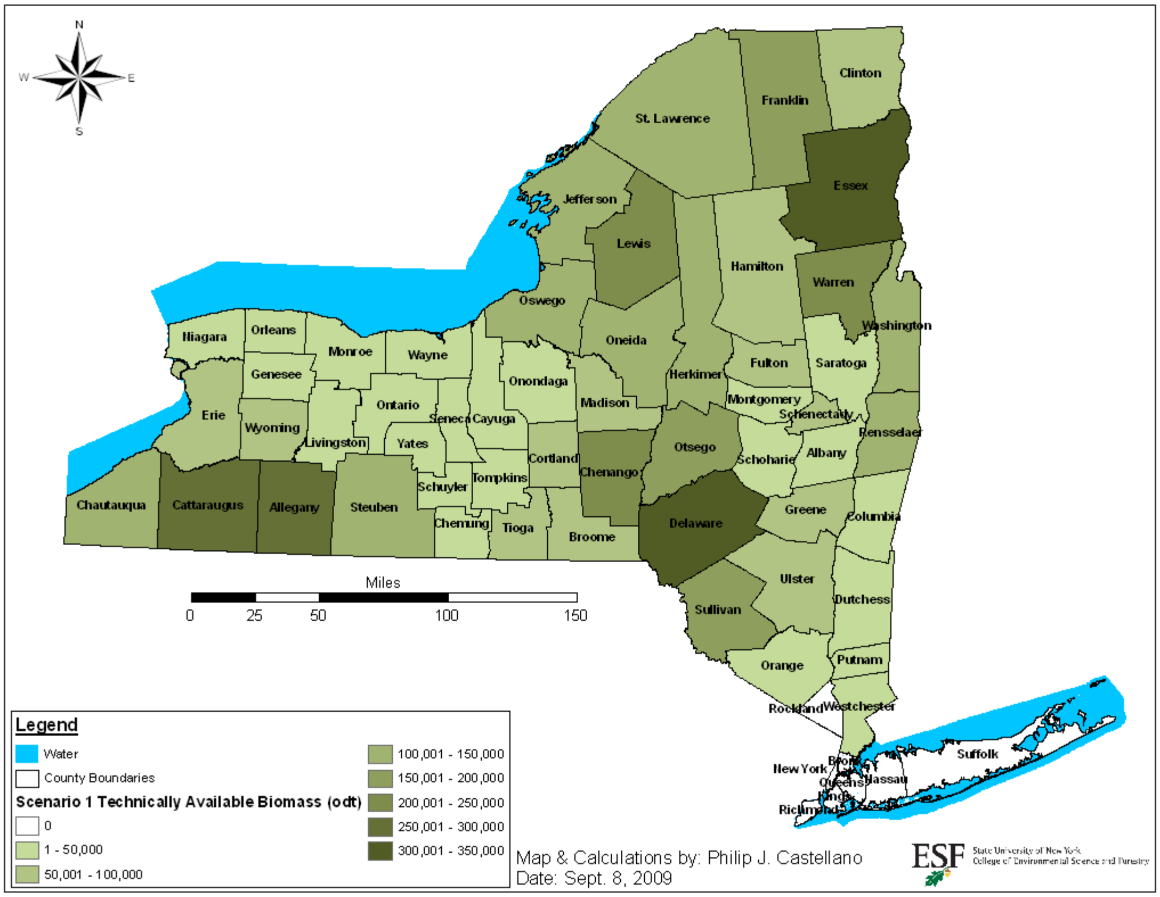


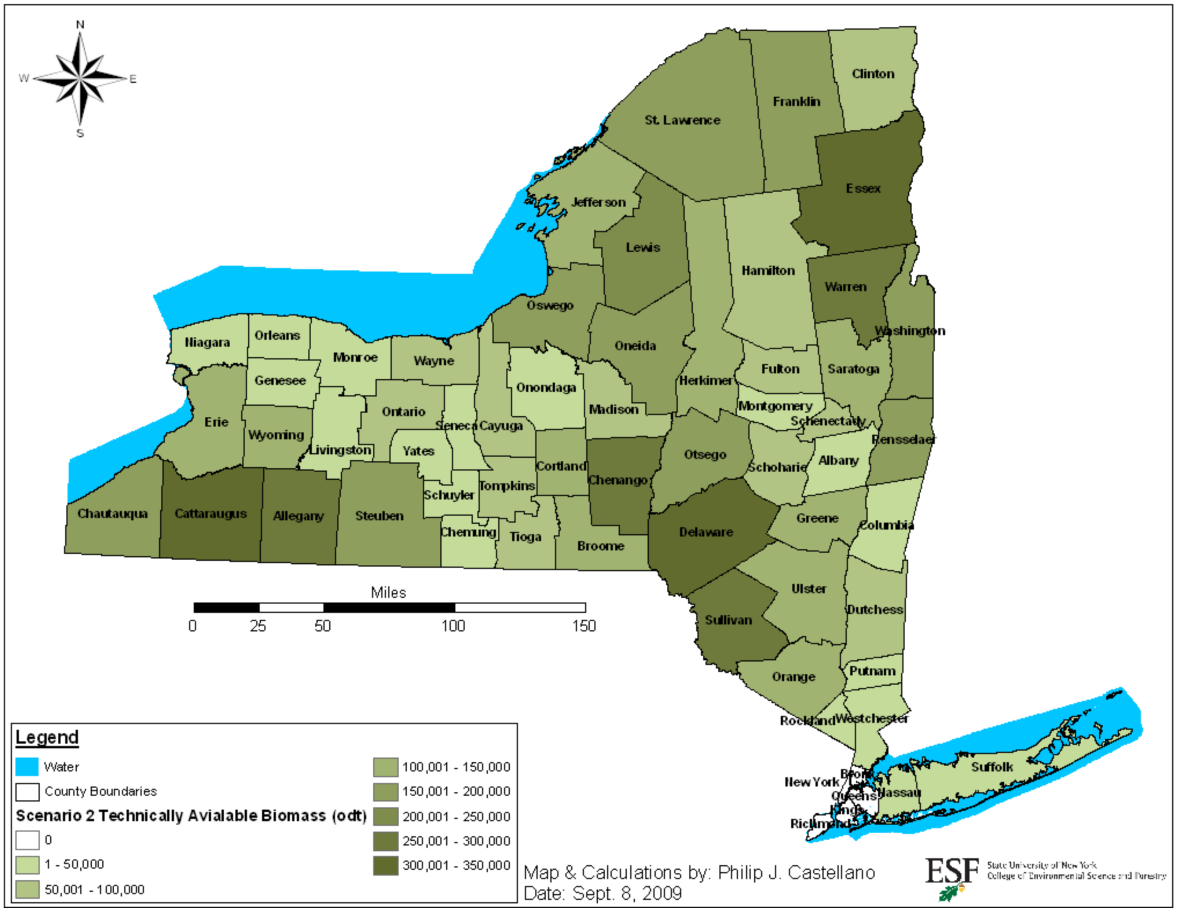
Figure E-D-4. Potentially available woody biomass from timberland in each county in New York for Scenario 1.

Potentially Available Woody Biomass from Forests for Scenario 2 and 3

Under the conditions for Scenario 2 & 3, over 6.4 million odt of woody biomass could be available on an annual basis for the production of biofuels or other bioenergy products. This is an increase of 33.5% over the amount of woody biomass under Scenario 1. Hardwoods were still the dominant source of biomass, making up 73.2% of the potential supply. The all live merchantable category was still the main source of material, accounting for 53.8% of the total, followed by the noncommercial species (32.4%) and total recoverable material (14.2%)

In Scenario 2 and 3, three counties (Cattaraugus, Delaware, and Essex) had the potential to produce more than 300,000 odt of woody biomass per year and five counties (Allegany, Chenango, Lewis, Sullivan, and

Warren) had the potential to produce more than 200,000 odt (Figure 5). Fifteen counties had the potential to produce less than 50,000 odt per year of woody biomass from timberland under this scenario.



Map & Calculations by: Philip J. Castellano
Date: Sept. 8, 2009

Figure E-D-5. Potentially available woody biomass from timberland in each county in New York for Scenarios 2 and 3.

Discussion of Limitations of Woody Biomass Assessment

The sustainable yield model used in these assessments was developed by Vickery et al. (2009) in a five county region in central New York. The range of SYM potential across this region ranged from 13.4% in Onondaga to 82.6% in Chenango. However, the model was developed at a smaller scale, the township level, where the SYM potential was from 0 to 100%. The application of the SYM model at the township level across New York State was an effective way to make use of this tool.

While the upper limit on the road density that limited any sustainable yield of forest products was fairly clear in the SYM model, there was a degree of uncertainty in the middle range values of the model. This combined with the fact that the model was developed in a limited geographical area in central New York raises concerns about the validity of the model in other parts of the state where landowner attitudes, regional economics and local policies related to forest management and harvesting might be different. In order to increase the level of confidence in the use of this model across the entire State it should be tested and refined for other regions.

The ability of the SYM model developed by Vickery et al. (2009) has advantages over other approaches that have been used to estimate the amount of woody biomass available from forests. A key aspect of this is the township scale at which the model was developed and can be applied. A common approach for adjusting the technically available biomass figures to get an idea of potentially available biomass is to make use of statewide figures related to landowner attitudes about forest management and harvesting (e.g. Kelty et al. 2008). A limitation of this approach is that the same factor is applied across the entire State, although there are regional differences in socioeconomic conditions. Analyses of statewide attitudes about forest management in the National Woodland Owner Survey (NWOS) are based on a relatively small sample of 650. Due to the relatively small sample it is difficult to identify regional differences in landowner attitudes. In addition, the questions asked in this survey are not specifically focused on harvesting for biofuels or bioenergy, so interpretation of the results from the survey is required in order to come up with a Statewide figure. The use of the SYM model allowed potentially available woody biomass figures to be developed on a county-by-county basis, which was essential for the siting model that was being developed and run by other parts of the team.

A basic assumption used in determining the amount of technically available woody biomass from timberland is that the amount of woody biomass removed for traditional forest products and biofuels or other end uses does not exceed the net annual growth rate at the county level. This requires estimates of mean forest growth rate per acre across State's timberland. The USFS FIA data is the best available information for the assessment of technically available amounts of woody biomass from forests in New York, but it has limitations that should be recognized. Each FIA inventory plot represents almost 6,000 acres, which allows for reasonably accurate data to be generated at the county level, but summarizing data at a smaller scale introduces large amounts of variation. While the data presented is effective for statewide assessments, the data is not spatially precise enough to be used for project-specific assessments. Other approaches to assessing potential woody biomass supplies for project specific supply sheds should be used including both spatial (Castellano et al. 2009) and socioeconomic tools.

The sampling framework and frequency of sampling for FIA data in New York has been undergoing a transformation since 2002 when a rolling schedule was implemented. While this will improve the dataset, it has created a period of time when some data are not available. For example, up to date net annual growth rates will not be available until the second round of data collection using the new protocol is completed in 2011-2012. The net annual growth rate used for these calculations was based on FIA data collected in 1993. While net annual growth rates across the state do not change dramatically over time, small changes will have some effect on the technically available biomass figures.

Data for mortality was not included in the assessments of the amount of technically available biomass across the State. This data is available from the FIA data set and indicates that there are about 3.3 million odt of mortality per year in New York forests. However, it is hard to determine how much of this woody biomass is potentially available when a forest stand is harvested. There are some estimates of how long dead trees remain standing and in sound condition in northern hardwood forests (e.g. Siccima et al. 2007), but this data is limited from areas with frequent and intensive surveys. The available data suggests that dead trees remain standing for 7.5 years (tree is dead but most branches are still present) and 15 years for snags (dead trees without major branches or broken off above breast height) (Siccima et al. 2007). The FIA data does not provide these types of classifications and the time that dead trees remain in the forest generally exceeds the recommended reentry time for typical harvesting techniques across the State (15-20 years). In addition, one of the main issues related to additional biomass harvests from forest is the removal of dead wood, including coarse and fine woody debris and snags, which are essential for maintaining nutrient cycling and biodiversity in forest (Evans and Perschel 2007). Most of the forest biomass harvesting guidelines that have been developed in the U.S. have recommended that some portion of woody debris and snags be left on site. The decision to not account for the woody biomass that could be obtained from mortality also means that these important concerns are can be addressed within the context of these estimates. Decisions on how much material to leave on site should be one of the issues discussed in the context of biomass harvesting guidelines that are being developed in New York State as part of the updating of Best Management Practice Guidelines (see discussion of this topic in Appendix E-E). The application of these types of guidelines needs to occur at the stand level, not the county scale that was used in this assessment. However, by not including biomass figures for mortality in this assessment, there is the potential to meet biomass harvesting guidelines that are in place in other states.

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Forest Inventory Analysis Terminology

Timberland: Forest land producing or capable of producing crops of industrial wood (more than 20 cubic feet per acre per year) and not withdrawn from timber use (formerly known as commercial forest land).

Merchantable biomass: The main stem of all species > 5” d.b.h. between a 1-foot stump height and a 4” top diameter (outside the bark), including rough and rotten culls (same as all live merchantable biomass).

Commercial species: Tree species presently or prospectively suitable for industrial wood products.

Growing-stock trees: Live trees of commercial species classified as sawtimber, poletimber, saplings, or seedlings; that is, all live trees of commercial species except rough and rotten trees.

Noncommercial species: Trees species of typically small size, poor form, or inferior quality that normally do not develop into trees suitable for industrial roundwood products.

All live merchantable biomass: All species > 5” d.b.h. between a 1-foot stump height and a 4” top diameter (outside the bark), including rough and rotten culls. **All live biomass**: All species (commercial and noncommercial) > 1” d.b.h., including rough and rotten culls.[22]

Logging residue: The unused portions of trees cut, or killed by logging, and left in the woods.

Net growth: The change, resulting from natural causes, in growing-stock volume during the period between surveys (divided by the number of growing seasons to produce average annual net growth). Components of net growth are ingrowth plus accretion, minus mortality, minus cull increment, plus cull decrement.

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[22] All live and all live merchantable biomass definitions are not given in the FIA database. These definitions were formulated by piecing together information from the FIA database and basic forestry knowledge.

Other removals: Unutilized wood volume of trees cut or otherwise killed by cultural operations (e.g. pre-commercial thinnings) or landclearings to non-forest uses. Does not include volume removed from the inventory by reclassification of timberland to productive reserved forest land.

Rotten tree: A live tree of commercial species that does not contain at least one 12-foot sawlog or two noncontiguous sawlogs, each 8 feet or longer, now or prospectively, and does not meet regional specifications for freedom from defect primarily because of rot; that is, more than 50% of the cull volume in the tree is rotten

APPENDIX E-E. BEST MANAGEMENT PRACTICES FOR FOREST BIOMASS HARVEST

By René H. Germain, Department of Forest and Natural Resources Management, SUNY-ESF

Publication of the first New York State Best Management Practices (NYS BMP) Field Guide for Water Quality was a collaborative effort between the following organizations: Department of Environmental Conservation (NYS DEC), Empire State Forest Products Association (ESFPA), Sustainable Forestry Initiative (NYS SFI), SUNY ESF and the Watershed Forestry Program. The content of the field guide has not been revised since the initial publication in 2000. In 2009, the Watershed Forestry Program, in cooperation with ESFPA and NYS DEC, is leading the effort to revise the field guide to reflect new BMP knowledge, technologies and equipment as well as changing forest management practices, including specific BMPs associated with harvesting woody biomass for energy use. There are plans to hold several public meetings around the State to solicit feedback on the contents of the revised field guide. Furthermore, a technical review panel has been assembled to provide technical input and review. Publication of the revised BMP field guide is expected in 2010.

Existing harvesting guidelines as described in New York State's Best Management Practices (BMP) Field Guide are relevant to biomass harvesting, but may not adequately address the impacts of increased removal of biomass from the forest and the associated harvesting systems required for implementation. The harvest of smaller diameter trees, low-grade stems, tops, woody shrubs, and deadwood often associated with woody biomass harvesting operations could have adverse impacts on soil productivity, wildlife habitat, biodiversity, residual stands, forest regeneration, aesthetics, and water quality.

- The potential loss of large volumes of coarse woody debris (CWD) and fine woody debris (FWD) is unique to biomass harvesting and could have significant impacts on nutrient availability and biodiversity. CWD is defined as tree tops, stumps, trunks or limbs greater than six inches in diameter at the large end. CWD provides critical habitat for numerous vertebrate species. FWD includes leaves, twigs, limbs, and other woody debris primarily from tree tops less than six inches in diameter at the large end. FWD provides habitat for hundreds of species of fungi, lichens, bryphytes, and arthropods (Carey and Johnson 1995; Butts and McComb 2000; Ecke et al. 2002; Gunnarsson et al. 2004).
- Biomass harvesting can remove up to twice the amount of nutrients as a conventional harvest, potentially resulting in declining long-term site fertility, ultimately impacting residual tree growth and future regeneration. Woody shrubs and herbaceous plants could also suffer the deleterious effects of nutrient losses. In general, it is possible to retain 30% of the FWD by scattering the tops from 20% of trees harvested (McInnis and Roberts 1994; Proe et al. 1994; Grigal 2004). However, the long-term effects on soil nutrients and site productivity are highly variable and site dependent (Tritton et al. 1987; Hendrickson 1988; Huntington and Ryan 1990; Hornbeck et al. 1990; Briggs et al. 2000; Grigal 2000; Kelty et al. 2008).

- Another characteristic unique to biomass harvesting is the potential to use woody shrubs, standing dead and dying trees – all of which contribute to wildlife habitat. The US Wildlife Service and others estimate that 120 species of birds, 140 kinds of mammals, and 270 species of reptiles and amphibians nest or forage in dead and decaying trees (Gurnel et al. 1995). Loss of this unique habitat could have short- and long-term impacts on wildlife.
- Biomass harvesting that is not part of a forest management plan could lead to unsustainable harvesting, high grading, and even land conversions. Conversely, when biomass harvesting is part of sustained yield management it provides markets for low-grade wood that could promote silvicultural practices, such as thinning designed to improve residual forest stands (Munsell and Germain 2007a). Also, when biomass harvesting is implemented with deliberate forethought and planning, wildlife species can benefit by the creation of early successional habitat (Lehmkuhl et al. 2002; Bies 2006). This is particularly important in a state such as New York where even-aged forests of 70 – 100 years dominate the landscape.
- Biomass harvesting may be driven by natural disturbances from wind, ice, fire, and insect or disease damage. Sanitation and salvage harvests conducted under the context of silviculture can lead to healthy forest regeneration.

Focus on Water Quality

Forestry's potential to cause water pollution via non-point sources has been well documented (Loehr et al. 1979; Scholze and McNeilly 1993; Schuler and Briggs 2000; Ellefson et al. 2001). BMP use is intended to reduce, over time, the rate of soil erosion and subsequent sedimentation and nutrient loading of water bodies resulting from timber harvests (Martin and Hornbeck 1994). BMPs are a preventative innovation. Preventative innovations are generally slowly adopted because the immediate benefits associated with their use are limited. Consequently, BMP implementation across the State is inconsistent. In regions such as the NYC Watershed, there are programs to facilitate implementation that usually result in higher BMP implementation (Munsell et al. 2006; Munsell and Germain 2007b). As profit margins narrow for loggers, primarily due to increasing fuel costs coupled with lower log prices, BMP implementation can fall victim to expediency.

Existing BMP guidelines are clearly appropriate for biomass harvesting, but are they adequate? Additional BMP measures may be necessary to address specific water quality impacts that are unique to biomass harvesting regimes. Principally, more wood fiber is potentially leaving the forest that would have been left on-site under traditional harvest conditions. This activity could adversely impact the "forest sponge" that serves to retain water and nutrients and deter erosion. The associated access system for logging machinery to secure smaller diameter trees, low-grade stems, tops, woody shrubs, and deadwood could impact a higher percentage of the harvest area, thus increasing the potential for compaction, drying, and disturbance of the organic layer thus accelerating surface run-off, erosion, and nutrient loading (Johnson and Curtis 2001). Harvest systems associated with woody biomass operations customarily include feller-bunchers working in concert with grapple skidders. Proper planning of skid trails is critical to minimize the area dedicated to the access system (Germain and Munsell 2005), particularly in forested riparian areas.

Several states, including Minnesota, Missouri, Pennsylvania, and Wisconsin have made a concerted effort to adopt harvesting guidelines and BMPs specific to woody biomass harvesting. In most cases, biomass harvesting guidelines supplement existing harvesting guidelines. Some states are currently reviewing potential guidelines, while other states and certification programs are using existing guidelines and standards. The table below is adapted from the Forest Guild's Assessment of Biomass Harvesting Guidelines. It summarizes different areas covered by both existing harvesting and supplemental biomass harvesting guidelines (Evans and Perschel 2009). New York has not adopted harvesting guidelines unique to woody biomass.

Category	**Item**	**States**				**Certification Programs**		
		MN	MO	PA	WI	S FI*	FSC*	TF*
Dead Wood								
	Coarse Woody Debris	√	√	√	√	√	√	
	Fine Woody Material	√	√	√	√			
	Snags	√	√	√	√	√	√	
	Stumps/roots	√	√	√	√			
Soil/Site Productivity								
	Nutrient retention	√	√	√	√	√	√	
Wildlife and Biodiversity								
	Wildlife	√	√	√	√	√	√	√
	Plants	√	√	√	√	√	√	√
	Biodiversity	√	√	√	√	√	√	√
	High Value Cons. Areas	√	√	√	√	√	√	√
Silviculture								
	Sustained Yield	√	√	√	√	√	√	√
	Regeneration	√		√	√	√	√	√
	Residual Stand Thresholds	√	√	√	√	√	√	
	Biomass Driven Harvest/High Grading	√	√	√	√			
	Sanitation/Salvage for Insects/Disease	√	√	√			√	
	Sanitation/Salvage for Fire	√	√	√	√		√	

	Conversion	√	√	√	√		√	
	Re-entry	√	√	√	√			
	Aesthetics	√	√	√	√	√	√	√
Water Quality								
	Planning	√	√	√	√	√	√	√
	Access System	√	√	√	√	√	√	√
	Sedimentation	√	√	√	√	√	√	√
	Nutrient Loading	√	√	√	√	√	√	√
	Riparian Areas	√	√	√	√	√	√	√
	Wetlands	√	√	√	√	√	√	√
	Soil Compaction	√	√	√	√	√	√	√
	Organic Layer Disturbance	√	√	√	√	√	√	√

* Certification standards are not specific to biomass harvesting.

Recommendations:

Future guidelines should protect the functions and values of forest resources during woody biomass harvesting activities. The following recommendations are based, in part, on biomass harvesting guidelines from Minnesota, Missouri, Pennsylvania, and Wisconsin.

These draft recommendations serve to supplement current guidelines as described in the NYS Forestry BMP Field Guide. Landowners and resource managers should consider all the various factors associated with local ecological conditions before adopting specific guidelines.

- Soil and Site Productivity - Retention of nutrients
    - Maintenance of coarse and fine woody debris
        - Retain approximately 10-20% of the FWD
        - On soils with less than 20-inches to bedrock, or sandy soils, try to leave one-third of the FWD
        - Avoid disturbance to forest floor and litter layer
        - Retain all stumps and roots (no exceptions)
        - Limit biomass harvesting on rocky sites with shallow soils
        - Limit whole tree harvesting on poor sites
        - Retain 2 – 5 non-commercial logs on forest floor per acre
- Wildlife & Biodiversity
    - Preservation of high value conservation areas
        - Avoid high value conservation areas
    - Consider habitat requirements for rare and threatened wildlife species

    - Case by case basis depending on species habitat requirements
  - Consider site conditions for rare and threatened plants
    - Case by case basis depending on species site requirements
  - Consider structural complexity throughout harvest area
    - Retain small uncut islands for vertical structure and landscape diversity
    - Retain 5% of a salvage area to maintain CWD and snags
      - exceptions should be made for human health and safety or issues associated with control of insect or disease outbreaks
  - Consider biodiversity at appropriate spatial scale
    - Plan for retaining biological legacies
  - Retention of snags
    - Retain cavity trees and replacement snags (> 12 inches)
      - Important Note: Maintain compliance with OSHA regulations when operating around hazard trees
- Silviculture
  - Must be part of sustained yield management based on documented growth and regeneration
  - Ensure regeneration
  - Biomass component should be part of the silvicultural prescription
    - Avoid re-entry into stand for biomass harvesting
  - Consider visual quality
- Land Conversions
  - Forestlands should not be converted to short-rotation woody crop production
  - Grassland/meadow conversion should consider value as habitat for rare and threatened wildlife species (see above)
- BMPs for Water Quality
  - Harvest plan should be complete prior to start of operation
  - Avoid biomass harvesting on slopes greater than 30%
  - Give special attention to access system (landing, roads and skid trails)
    - Should account for less than 10% of harvest area
  - Limit whole tree harvesting on less fertile sites to retain nutrient and avoid nutrient loading in streams and other water bodies
    - If conducting whole tree harvesting, retain slash on one-third of the site
  - Riparian Zones
    - Reduce amount of biomass available for harvest by 20% depending on site conditions

  - Reduce amount of basal area harvested in order to retain approximately 10 – 20 sq ft over the target residual basal area of remaining harvest area
  - Use cables as much as possible to pull logs out
  - Retain all existing deadwood
- Otherwise, follow BMPs as outlined in the NYS Forestry BMP Field Guide

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APPENDIX E-F. PRECISION NITROGEN MANAGEMENT (PNM) MODEL

By Dr. Jeffrey Melkonian, Department of Crop and Soil Sciences, Cornell University

Background. We are using the Precision Nitrogen Management (PNM) model (Melkonian et al., 2007) to simulate biomass production and associated nitrogen (N) losses to the environment of grain maize and coppiced willow production systems. The PNM model runs on a daily time-step and is composed of a soil process model (LEACHN, the N module of LEACHM (Hutson, 2003; Hutson and Wagenet, 1992)) that is linked to two crop growth/N uptake modules: a maize model (Sinclair and Muchow; 1995) and a coppice willow model (Eckersten et al., 2006). Both crop models have been parameterized for New York State. LEACHN is a process-based, one-dimensional model that simulates water and solute transport, and chemical and biological N and carbon (C) transformations in the unsaturated soil zone. Flows between different pools of N and C are simulated in each soil segment as well as on the soil surface. LEACHN is well suited for simulating soil N and C processes and has been extensively used and tested in several studies (Jabro et al., 1994; Jemison et al., 1994a, b; Lotse et al., 1992; Sogbedji et al., 2001a, b; Sogbedji et al., 2006). The rate constants in the equations describing nitrification, denitrification, manure mineralization, and plant residue mineralization were calibrated based on multi-year, replicated field experiments (Sogbedji et al., 2000; van Es et al., 2006). These field experiments were conducted on large, hydrologically isolated lysimeter plots located on two contrasting soil textural classes where nitrate-N leaching, crop N uptake, and changes in soil nitrate (NO_3)-N and ammonium (NH_4)-N levels were intensively monitored (Sogbedji et al., 2001a; Sogbedji et al., 2006).

The subroutines of the maize N uptake, growth, and yield model incorporate the effects of temperature, solar radiation, water supply, and parameters influencing the crop N budget during the three major phases of maize development: vegetative growth, anthesis, and grain fill (Muchow and Sinclair, 1991; Muchow et al., 1990; Sinclair and Amir, 1992; Sinclair and Muchow, 1995). Equations and descriptions of the processes in the model are presented in Sinclair and Muchow (1995). The maize N uptake, growth, and yield model has been well tested and provides a reasonable fit to total above-ground biomass and N uptake data that were collected over a range of conditions and were independent of those used in model development (Sinclair and Muchow, 1995). Several components of the maize N uptake, growth, and yield model (leaf appearance, sensitivity of leaf area development to soil water content and specific leaf N, and crop transpiration) were slightly modified for the climate and grain cultivars that are typical for New York State (Cox et al., 1990a; Jara et al., 1998; Cox et al., 1990b). Following these adjustments, we have found good agreement between measured and PNM model-simulated maize N uptake and yield for a number of locations in New York State.

Components of the coppice willow model include calculation of potential and actual transpiration using the approach described by Priestly and Taylor (1972), root water uptake (Riha, 2003), seasonal development of leaf area, biomass production estimates using a radiation use-efficiency approach, N uptake by the willow crop, and N and C dynamics associated with leaf fall. Impact of low soil moisture and soil N on willow biomass production are also included.

The PNM model is currently linked to the Applied Climate Information Service (ACIS) through the Northeast Regional Climate Center (Cornell University) to automatically access key drivers of the soil and crop processes (daily solar radiation, temperature, and precipitation) for any reporting station in the U.S., including New York State. Within the next few months, the PNM model will be modified to automatically access high resolution climate data (daily temperature and precipitation on a 4 km x 4 km grid) for the eastern U.S. to the 100th meridian (DeGaetano and Belcher, 2007; DeGaetano and Wilks, 2008). These data will allow application of dynamic simulation models like the PNM model to function at a much finer spatial resolution than is currently available via ACIS.

Methods. *Grain maize.* Grain maize growth/N uptake and environmental N losses were simulated for three soil textural classes: sandy loam, silt loam and clay loam. Yearly maize growth and N losses associated with maize production on the three soil textural classes were simulated for 40 years of climate data from six locations around New York State where significant maize production takes place: Albany, Binghamton, Buffalo, Burlington (Vermont/representative of the Champlain Valley), Massena, and Syracuse. These locations (with Burlington as a surrogate for the Champlain Valley of New York State) also represent different climate regions within New York State as defined by the Northeast Regional Climate Center. The cultural and management practices applied in the model simulations for each location were representative of current grain maize production in New York State on these three soil textural classes. These included two tillage practices (no tillage and spring tillage) and two fertilizer N practices (seasonal crop N requirement all applied at planting or split between a small application at planting (30 kg N/ha) with the remainder of the N applied as a sidedress application on June 29th). Total seasonal N applications for each soil textural class followed current recommendations for grain maize in New York State (Ketterings et al., 2003). Key outputs of the simulations were 35-year average reactive N losses to the environment (NO_3-N leaching losses and nitrous oxide N_2O-N production from denitrification and nitrification) from harvest to harvest. (The urea-ammonium nitrate-N and urea-N formulations used in the simulations were incorporated into the soil. Therefore, ammonia volatilization losses were negligible.) These outputs were averaged across the two tillage practices since the trends and absolute values between the tillage practices were similar.

Coppiced willow. Data from several studies by the College of Environmental Science and Forestry / State University of New York (SUNY-ESF) at their Tully research site were used to calibrate the willow model (Adegbidi, 1999; Volk, 2002; Tharakan et al., 2008). Following calibration, coppiced willow production and N losses associated with this production were simulated at the end of a three year rotation for several locations across New York State and in the Champlain Valley of Vermont where willow growth and yield were monitored (Only data from clone SV-1 were used for the calibration and model performance testing. Previous clonal evaluations by SUNY-ESF have demonstrated that SV-1 is productive across a range of sites in New York State.). Coppiced willow production at these locations generally followed the guidelines developed for New York State (Abrahamson et al., 2002). For the first rotation, these guidelines include spring planting (year 0), coppicing at the end of the planting year, a 112 kg N/ha application in the spring of the year following coppicing (year 1) and harvest at the end of year 3. For subsequent three year rotations, an additional 112 kg N/ha application in the spring of the first year (following harvest) of each rotation and harvest at the end of year 3. Key outputs of the simulations were reactive N losses to the environment (NO_3-N leaching losses, NH_4-N volatilization losses, and N_2O-N production from denitrification and nitrification) over the rotation (spring, year 1 to harvest at the end of year 3).

For both the maize and willow simulations, the N_2O-N component of total denitrification was estimated based on the percent soil saturation (water filled pore space, WFPS). The reported ratio of N_2O -N to total denitrification ranged from 0.15 - 0.8 at 60% WFPS (Weier et al., 1993; Gillam et al., 2008), 0.25 - 0.9 at 75% WFPS (Weier et al., 1993; Gillam et al., 2008) and 0.24 - 0.35 at 90% WFPS (Weier et al.). All simulations were done assuming mid-range values for these ratios. Nitrous oxide-N production from nitrification was simulated in a similar manner where N2O-N production associated with nitrification is calculated based on factors (obtained from the literature) that vary with WFPS (Bateman and Baggs, 2005; Mathieu et al., 2006).

Note that all simulations were done assuming unrestricted drainage from the root zone.

Results. *Grain maize.* The average yearly NO_3-N leaching losses (Figure 1a-c) and N_2O-N production (Figure 2a-c) were primarily a function of soil textural class.

Leaching was the dominant N loss process on the coarser textured soil. Averaged across locations, N leaching losses ranged from approximately 45 – 50 kg NO_3-N ha^{-1} yr^{-1} on the coarser textured soil (Figure 1a) to approximately 10 – 11 kg NO_3-N ha^{-1} yr^{-1} on the finer textured soil(Figure 1c).

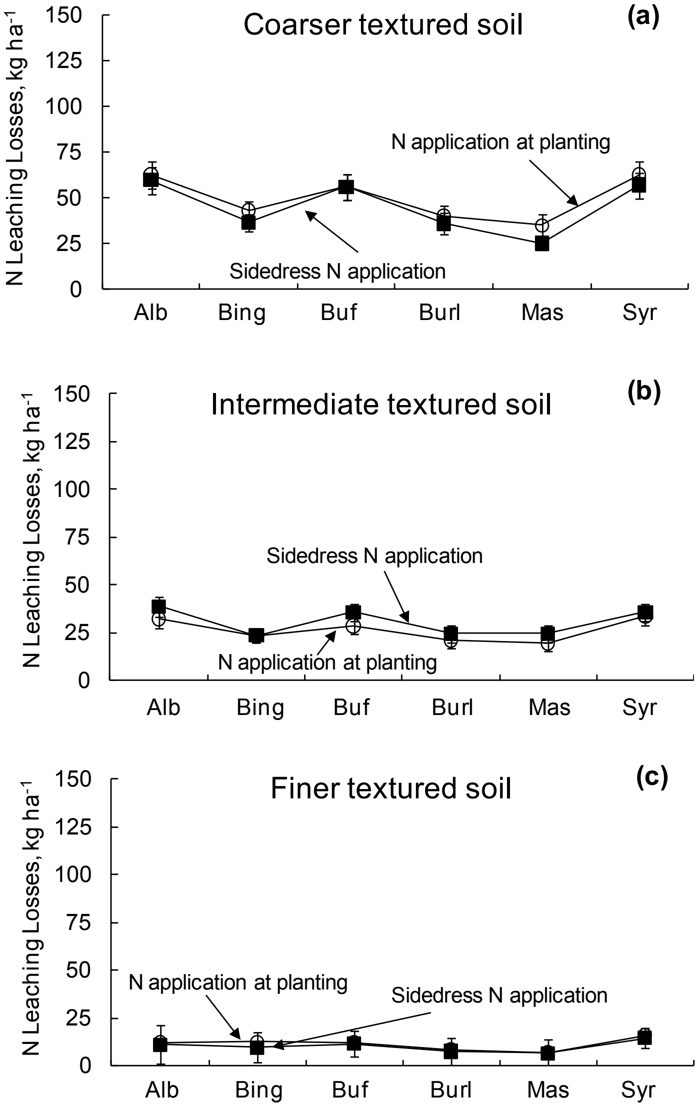

Figure E-F-1. Simulated yearly (10/20/year n – 10/20/year n+1) nitrate-N leaching losses (kg NO_3-N ha^{-1} yr^{-1}) associated with current management N practices for grain maize production across three soil textural classes: (a) coarser textured; (b) intermediate texture; and (c) finer textured. Losses are averages (+/- s.e.) of 35 climate years at five locations in New York State and one in the Champlain Valley of Vermont ('Alb'=Albany, 'Bing'=Binghamton, 'Buf'=Buffalo, 'Burl'= Burlington, 'Mas'=Massena, 'Syr'=Syracuse). Losses at each location are shown for two N management practices: current recommended seasonal N requirement applied at planting ('N application at planting') and applied in a split application ('Sidedress N application').

Nitrous oxide-N loss (largely associated with denitrification) was the dominant N loss pathway on the finer textured soil (Figure 2c). Nitrous oxide N loss was negligible on the coarser textured soil (Figure 2a). Leaching and denitrification losses were intermediate for the intermediate textured soil, contributing about equally (approximately 25 kg N ha^{-1} yr^{-1} from each loss pathway) to the total N losses on this soil textural class (Figures 1b, 2b). Nitrous oxide N losses are generally higher on finer textured soils. These soils drain more slowly than coarser textured soils, remaining for a longer period of time in the % WFPS range where denitrification occurs. In addition, the finer textured soils tend to have higher soil organic matter (SOM) contents, providing more soil C for denitrification (denitrification is a microbial-driven process where soil C is the energy source for the denitrifiers).

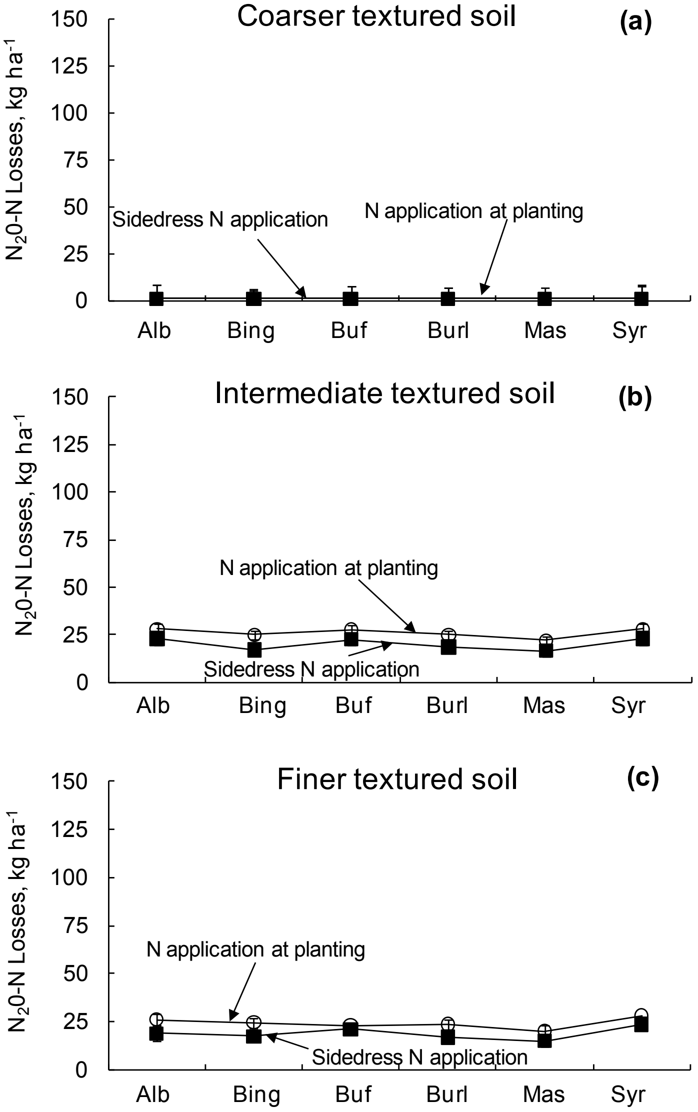

Figure E-F-2. Simulated yearly (10/20/year n – 10/20/year n+1) N_2O-N losses (kg (N_2O-N) ha^{-1} yr^{-1}) associated with current management N practices for grain maize production for three soil textural classes: (a) coarser textured; (b) intermediate texture; and (c) finer textured. Losses are averages (+/- s.e.) of 35 climate years at five locations in New York State and one in the Champlain Valley of Vermont (‘Alb’=Albany, ‘Bing’=Binghamton, ‘Buf’=Buffalo, ‘Burl’= Burlington, ‘Mas’=Massena, ‘Syr’=Syracuse). Losses at each location are shown for two N management practices: current recommended seasonal N requirement applied at planting (‘N application at planting’) and applied in a split application (‘Sidedress N application’).

Location and fertilizer N practice had secondary impacts on N losses. Location primarily affected the extent of NO_3-N leaching losses (N_2O-N losses varied little with location, Figures 2a-c). N leaching losses were lowest at Massena and highest at Syracuse with the effect of location greatest for the coarser textured soil (Figure 1a). Generally, these location differences in long-term average N leaching losses were related to seasonal precipitation and average temperatures at the different locations. Massena and Burlington, with lower NO_3-N leaching losses, have lower long-term average seasonal precipitation (900 and 909 mm, respectively) compared to Syracuse (1013 mm), Buffalo (1020 mm) and Albany (981 mm), locations with higher NO_3-N leaching losses. In addition, long-term monthly average temperatures are generally lower at Massena and Burlington compared to the other locations, resulting in less SOM mineralization and less total inorganic N in the soil at these locations. It should be noted that year-to-year differences in N leaching and N losses generally can vary widely depending on the distribution and intensity of precipitation in a given year, regardless of the location.

In general, there were slightly lower NO_3-N and N_2O-N losses when fertilizer N applications were split (starter N and sidedress N) compared to applying seasonal crop N needs at planting. This is because the active N uptake phase by maize does not occur until 5 – 6 weeks following planting. Nitrogen applied at planting, therefore, remains in the soil profile for this time period without significant crop N uptake and is subject to leaching and denitrification. Split N applications largely avoid these early season losses. Again, it should be noted that year-to-year differences in N leaching and N losses generally can vary widely depending on the weather conditions in a given year. (The PNM model is currently being used to assess the impact of early season weather on crop-available soil N for a given location and, based on this assessment, suggest adjustments to fertilizer N rates. Over the long term, this should result in lower N losses to the environment.)

Summary. Total reactive N losses from grain maize under current N management practices ranged from approximately 30-35 kg N ha^{-1} yr^{-1} (finer soil texture class) to approximately 45-50 kg N ha^{-1} yr^{-1} (coarser /intermediate soil texture classes). It should be noted that the current recommended N rate is highest on intermediate textured soils since they generally have a higher yield potential than the coarser and finer textured soils. This, combined with relatively higher soil organic matter (SOM) contents and conditions more favorable to SOM mineralization, account for the slightly higher N losses on this soil textural class. (PNM model simulations suggest that it may be possible to reduce N rates on both coarse and intermediate textured soils with little or no yield loss.)

Coppiced willow. Leaching losses (kg NO_3-N ha^{-1} yr^{-1}), ammonia volatilization losses (kg NH_4-N ha^{-1} yr^{-1}) and N_2O-N losses (kg N_2O-N ha^{-1} yr^{-1}) are shown for three year coppiced willow rotations at several locations in New York State (Table 1). These locations were selected because modeled and measured three year rotation biomass yields were reasonably close. Percent N in harvested biomass is relatively well established for the clone SV-1 and this value was used to estimate N removal in the harvested biomass into the N component of the willow model. We assumed, therefore, that modeled N recycling and N losses were reasonable estimates of the actual values over the rotation for these locations.

Total N losses for five of the seven site trials ranged from approximately 30 to 50 kg N ha^{-1} yr^{-1} (Table 1). Two of the site trials ('Canastota, NY-2-rotation 1' and 'Canastota, NY-2-rotation 2') had higher total N losses (77 kg N ha^{-1} yr^{-1} and 88 ha^{-1} yr^{-1}, respectively). The soil series where these trials were conducted had relatively higher SOM (7 – 12% compared to 2 – 5%) over the entire root zone compared to the soil series in the other trials. This high SOM resulted in significantly greater simulated SOM mineralization, higher levels of NO_3-N and NH_4-N in the root zone N, and larger potential N losses for these trials. It should be noted that, at least for agricultural soils, SOM values are more often in the range of 4 – 6%. Therefore, N losses in the range of 30 – 50 kg N ha^{-1} yr^{-1} may be more representative of coppiced willow production systems if we assume that production occurs on agricultural fields.

Table E-F-1. Simulated yearly average N leaching losses (kg NO_3-N ha^{-1} yr^{-1}), ammonia volatilization losses (kg NH_4-N ha^{-1} yr^{-1}), and nitrous oxide losses (kg N_20-N ha^{-1} yr^{-1}) over a three year rotation for several coppice willow trials in New York State where modeled and measured rotational yields were similar. Note that the N-loss data were calculated from the time of N fertilizer application (spring, year 1 (planting year = year 0) to the harvest at the end of year three (each rotation is 3 years).

Location	Soil textural class	Leaching loss (kg NO_3-N ha^{-1} yr^{-1})	Ammonia volatilization (kg NH_4-N ha^{-1} yr^{-1})	Nitrous oxide loss (kg N_20-N ha^{-1} yr^{-1})
Tully, NY-1	Silt loam	21	4	4
Tully, NY-2	Silt loam	26	3	6
Sheridan, NY	Clay loam	13	4	34
Wolcott, NY	Sandy loam	29	1	<1
Canastota, NY-1	Clay loam	23	3	23
Canastota, NY-2-rotation 1	Clay loam	27	5	45
Canastota, NY-2-rotation 2	Clay loam	33	5	50

Yearly N total N losses were similar between the maize and coppice willow systems (excluding the two high N loss coppiced willow sites ('Canastota, NY-2-rotation 1' and 'Canastota, NY-2-rotation 2') despite lower N inputs in the form of fertilizer in the coppiced willow systems. This may be explained in part by the significantly lower average yearly crop N uptake by coppiced willow compared to maize. This resulted in somewhat higher soil N levels in the root zone in the willow that are then subject to losses. This lower crop N uptake is the result of two factors: lower average yearly biomass yields in the coppiced willow systems compared to maize, at least for the sites examined here, and lower %N in the harvested biomass (dry weight) for coppiced willow compared to maize (0.29% for willow; 1.2 – 1.7% for maize grain).

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APPENDIX E-G. POTENTIAL FEEDSTOCKS FROM URBAN WASTE

By Matthew Guenther and Mark Boustouler, Pace Energy and Climate Center

Introduction

This section will evaluate urban waste streams for their potential as biofuel feedstocks. These waste streams include potential biodiesel feedstocks, such as yellow grease, and potential ethanol feedstocks, including yard waste, paper waste, food waste, misc. woody waste, and other cellulosic material. The goal is to find out how much urban waste biomass is being generated in New York State, how it is currently being disposed, and what types of urban biomass are appropriate for use as ethanol or biodiesel feedstocks. Once these questions are answered a determination can be made as to whether urban biomass could become a sustainable source of biomass feedstocks for New York State.

In conducting the evaluation the following assumptions were made:

- All biomass material currently being recycled would continue to be recycled in the future. Thus only material that is destined for landfills or incinerators was considered.
- If credible estimates were available of increased recycling rates in the future, this additional biomass was assumed not to be available for biofuel production.
- We examined potential feedstocks only for ethanol or biodiesel.
- This report uses the EPA's 2007 Municipal Solid Waste (MSW) national report definition of MSW as "everyday items such as product packaging, grass clippings, furniture, clothing, bottles, food scraps, newspapers, appliances, and batteries. Not included are materials that also may be disposed in landfills but are not generally considered MSW, such as construction and demolition materials, municipal wastewater treatment sludges, and non-hazardous industrial wastes."
- None of the reports reviewed for this analysis specifically listed percentages of biomass in the urban waste stream, therefore such percentages and total biomass figures were inferred based upon other information. Paper, yard waste, food scraps, household wood waste, or yellow grease were considered to be acceptable biomass categories.
- All tons mentioned are short tons.

A comprehensive evaluation of the potential for urban waste streams as biofuel feedstocks in New York State is challenging due to lack of comprehensive data on urban wastes. This study used data from four waste characterization studies conducted in New York State, estimates from the 2000 United States Environmental Protection Agency (USEPA) national waste characterization study, and estimates of yellow grease production from a study by the New York State Energy Research and Development Authority (NYSERDA)..

Waste Characterization Studies Ethanol from MSW

OCCRA

The Onondaga County Resource Recovery Agency (OCRRA) conducted a waste characterization study in 2005 (Dvirka and Bartilucci Consulting Engineers, 2006). In the OCRRA study approximately 47.1% of 13,600 pounds of MSW sampled during a two-week period, or 6,406 pounds was biomass that could potentially be used as a feedstock for ethanol. The entire 6,406 pounds would not necessarily be used as a feedstock, as some of this material could have been recycled under current Onondaga county programs.

NEST

NorthEast-SouthTowns (NEST), a group of municipalities in Western New York State, also conducted a waste characterization study (NEST, 2003). This study provides a breakdown of the type of material recycled, percentage recovered, and price received for selling the material on the market. This study incorporated data on MSW generation and recovery rates for some municipalities, as well as estimates for municipalities that did not have data, based on EPA's 1998 national figures. It is estimated that out of a population of 433,377 a total of 427,529 tons of MSW is generated annually. The breakdown of the biomass portion is as follows:

- Paper waste 142,492 tons (37.3%)
- Wood waste 19,008 tons (5%)
- Food waste 37,824 tons (9.9%)
- Yard waste 52,845 tons (13.8%)

The recovery rate for each item is as follows:

- Paper waste 58,304 tons (40.9%)
- Wood waste 846 tons (4.4%)
- Food waste 436 tons (1.2%)
- Yard waste 29,412 tons (55.7%)

The estimated total biomass in NEST's MSW was approximately 252,169 tons (59% of the waste stream); of the total biomass present approximately 88,998 tons or 35.29% were recovered for recycling or composting. This leaves 163,171 tons of biomass or 38% of MSW potentially available as a biofuel feedstock. See Figure 1, below.

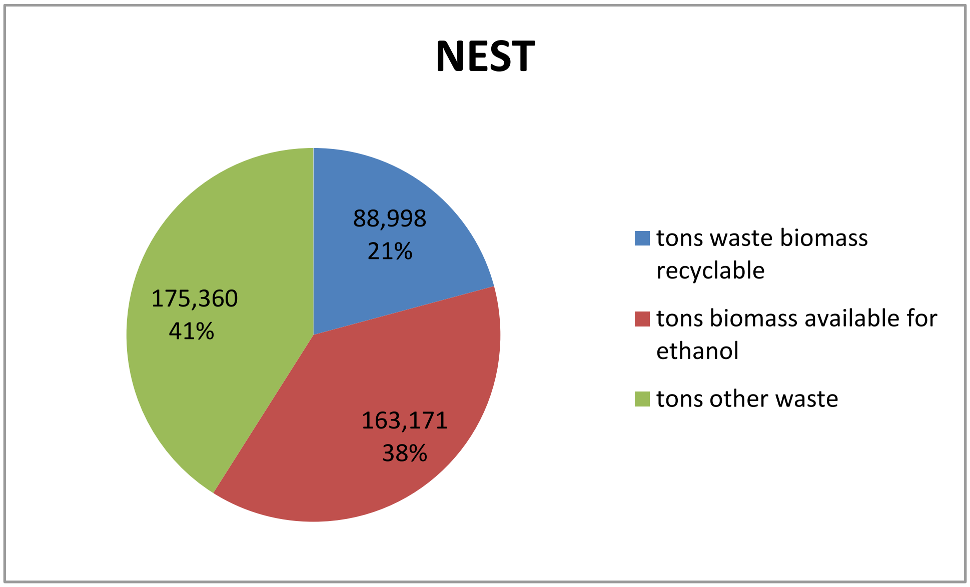

Figure E-G-1. Recoverable Biomass in NEST Study.

NYSDEC

A study by the New York State Department of Environmental Conservation (NYSDEC) characterized MSW in NYS, though it is less detailed than the NEST report. When this study was conducted the population of NYS was 18,976,816 (US Census Bureau). According to this study a total of 29.7 million tons of MSW was generated. Of this total it was estimated:

- Paper waste 11,583,000 (39%)
- Yard waste 2,673,000 tons (9%)
- Food waste 3,267,000 tons (11%)
- Total MSW biomass waste 17,523,000 tons (59%)

This study estimated that 12.9 million tons of MSW were recovered, but did not report the percentage for the different categories of waste (NYSDEC Division of Solid & Hazardous Materials, n.d.).

New York City

New York City (NYC) conducted a waste characterization study in 2005 (NYC Department of Sanitation). Except for the paper category, the material categories were slightly different than the other cited studies, but the report does give approximate waste stream composition. It was estimated that a total of 2,755,804 tons of refuse is generated in NYC in 2005. During this time New York City's population was approximately 8.3 million (NYC Department of City Planning).

Annual MSW biomass waste estimates are as follows:

- Paper waste 642,654 tons (23.3%) Although, 15% of the total waste stream was paper that could be recycled. Assuming that recycling programs expand to capture this recyclable paper, only 8.3% of the waste paper stream is suitable for diversion to ethanol production.
- Yard waste 141,648 tons (5.14%)
- Food waste 589,742 tons (21.0%)
- Woody waste 27,558 tons (1%)

The total biomass portion of NYC's MSW is 50.9%, however, presumably only 35.9% of the urban waste stream is available for diversion to ethanol production (NYC Department of Sanitation). See Figure 2, below.

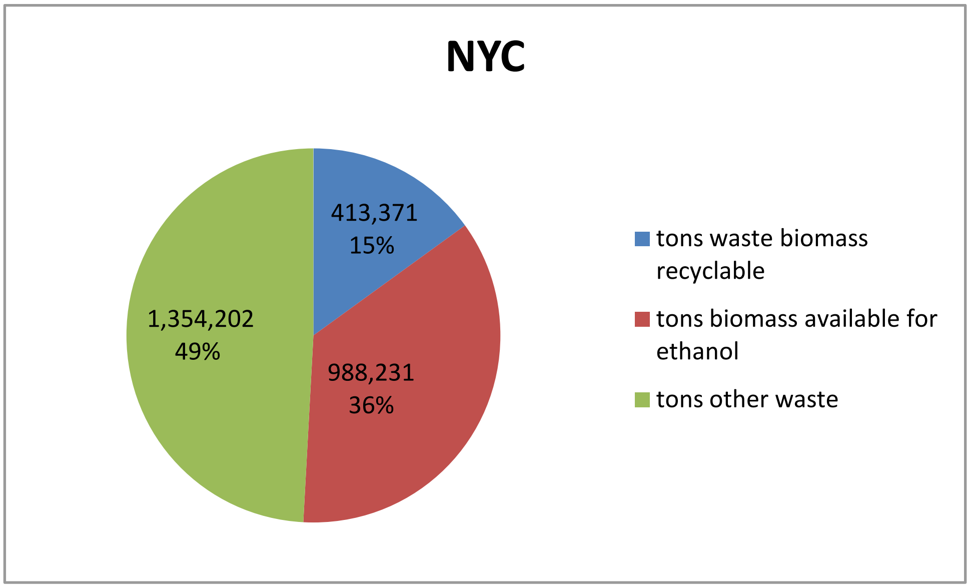

Figure E-G-2. Recoverable Biomass in NYC study.

EPA

In 2007 the EPA published an updated version of its waste characterization study for the U.S. (EPA, 2008). This study provides a useful comparison to waste characterization studies done in New York State. The biomass portion of MSW in the U.S. is as follows:

- 12.8% was yard waste,
- 5.6% was wood waste,
- 12.5% was food waste, and
- 32.7% was paper waste.

This equates to an approximate total biomass portion of 63.6% in U.S. MSW. Accounting for the amount of biomass that was recovered for other uses approximately 36.7% of the total MSW would have been suitable biomass for ethanol production. This figure is in close proximity to the two calculated percentages of biomass available in New York State. See Figure 3, below.

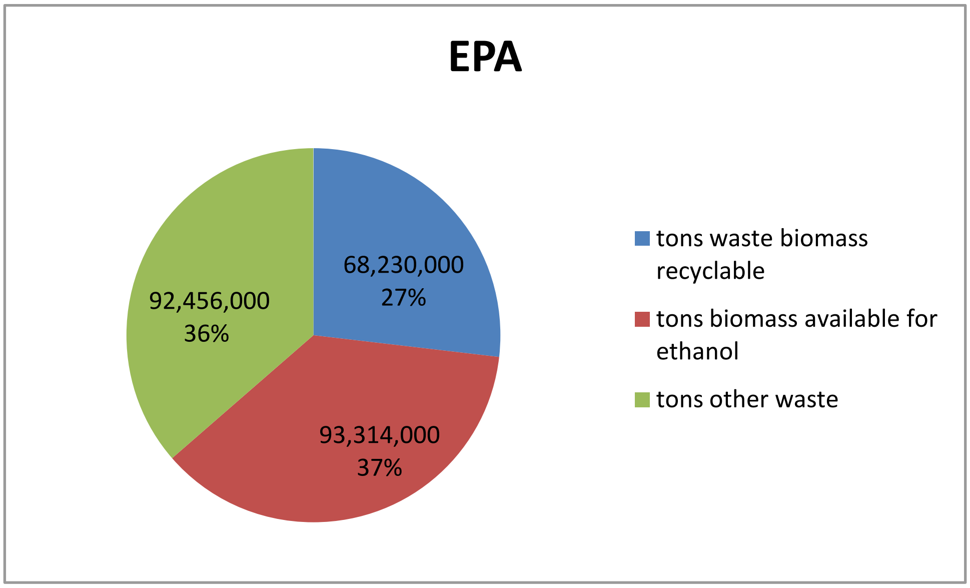

Figure E-G-3. Recoverable Biomass in USEPA Study.

MSW to Ethanol Production Potential

This section is here to give the reader an idea about the ethanol production potential of MSW. The 2000 NYSDEC study offers Statewide averages of percent material compositions in MSW. For this reason the calculated biomass tonnage totals using these percentages were used for this section.

According to Appendix H of this report the most suitable technology for MSW to ethanol conversion would be gasification, since practically any form of biomass can be gasified. However, there is a lack of information regarding this specific technology in regard to MSW, so the choice was made to use conversion factors for LCEt H/F (lignocellulosic to ethanol by hydrolysis and fermentation), which have known conversion factors, also in Appendix H.

Unfortunately, LCEt H/F technology does not allow for conversion of all waste biomass. Only very pure lignocellulosic waste biomass can be used, such as mixed paper waste and yard waste. Hence, only mixed paper waste and yard waste tonnages were used for conversion to ethanol. The conversion factors for mixed paper and yard waste to ethanol using LCEt H/F with three different pre-treatment processes are reproduced below from Appendix H in Table 1.

Table E-G-1.

	Units: Gal Ethanol/dry ton				
Feedstock	Short-term (dilute acid hydrolysis)	Mid-term (dilute acid Hydrolysis)	Mid-term (steam explosion)	Long-term (dilute acid hydrolysis)	Long- term (LHW)
Mixed Paper	76.8	86	83.5	92.1	98.8
Yard Waste	63.9	70	68.6	74.4	73.4

(For additional details on ethanol conversion technologies please see Appendix H)

It should be noted that very rough estimates were used for available paper waste and yard waste. According to the NYSDEC study roughly 11,583,000 tons of paper is in the MSW waste stream, along with 2,673,000 tons of yard waste. Since the NYSDEC study did not list specific recycling rates or recovery rates for these two items, an estimation for recycling of paper waste was made based upon averages of the NEST waste characterization study and the NYC waste characterization study. Only the NEST study listed a recovery rate for yard waste, but it seemed like a good representation of a Statewide average. Actual yard waste recovery rates are difficult to estimate, since some people backyard compost rather than sending it to a facility. The assumed recycle rate for paper was 53% and the recovery rate for yard waste (i.e. composting) was 56%. The paper recycling and yard waste recovery rate are reflections of current waste management policies, so the actual future availability of MSW biomass resources will be highly dependent on future waste management strategies.

In addition, moisture content was assumed for each feedstock. Figures for moisture content of paper waste and yard waste in MSW were taken from the "MSW Learning Tool" Website (University of Central Florida). Mixed paper waste had a moisture content of around 6%, while yard waste had moisture content of 60%. Moisture content of MSW will vary seasonally and regionally, but a figure for NYS was not found.

The recycling and recovery rate, along with the moisture content of these two feedstocks were calculated in Table 2 below that depicts how many gallons of ethanol will be produced from mixed paper and yard waste based upon their respective tonnage from the 2000 NYSDEC study. The reader should understand that these numbers are to give an idea of the potential of converting MSW to ethanol, but are still very rough estimates.

Table E-G-2.

		Units are gallons of ethanol				
Waste category	2000 NYSDEC waste figures in tons	Short-term (dilute acid hydrolysis)	Mid-term (dilute acid Hydrolysis)	Mid-term (Steam Explosion)	Long-term (dilute acid hydrolysis)	Long-term (LHW)
Mixed paper	5,158,752	396,192,137	443,652,653	430,755,774	475,121,039	509,684,676
Yard waste	474,114	30,295,896	33,187,992	32,524,232	35,274,095	34,799,980
Totals		426,488,032	476,840,645	463,280,006	510,395,134	544,484,656

Discussion on Ethanol Production Potential from MSW

Based on the studies discussed above, approximately 54% of New York State's MSW is suitable biomass feedstock for production of ethanol. The calculated national average was around 63.6%. However, the amount actually available for biofuel production will depend on material recovery rates, which are dependent on waste management policies. Each report states that material recovery rates could be higher, and each New York State study indicates that there are plans to increase the recovery rate for most biomass material, especially composting programs, which would reduce the quantity of food waste and yard waste available for biofuel production.

There were only two studies from New York State that offered enough information to make an estimate for percentage of waste biomass available for ethanol production: the NYC waste characterization study and the NEST study. Estimated total biomass available for ethanol production from the overall MSW stream was 36% and 38% respectively, and the estimated averaged from the EPA study is 37%. Hence, it can reasonably be expected that the percentage of New York State's MSW available for ethanol production would be around the same percentage. According to our rough estimate, ethanol yield from paper and yard waste is 426,488,032 gallons in the short term and 544,484,656 gallons in the long term with advanced pre-treatment technologies.

A complete and comprehensive analysis of the potential for MSW as a feedstock for ethanol would require an economic and resource recovery policy analysis of each county in New York State, similar to the study conducted by NEST. Such an analysis would clarify the competing uses for biomass in MSW and its corresponding market prices, conversion factors for MSW to ethanol, the market price of ethanol, and infrastructural/capital costs. In addition, other waste biomass resources are potentially available, but are not considered part of the MSW stream. For example, construction and demolition debris is a viable option, along with biomass waste from other industrial processes. However, such a study should evaluate the full environmental impacts of diverting waste destined for landfills and incinerators to ethanol production rather than recycling.

This section has only touched the tip of the iceberg for the potential of non-agricultural biomass waste to be converted into biofuels. There is a need for future studies of this potential biofuel feedstock.

Biodiesel from Yellow Grease

For yellow grease, enough information was available from NYSERDA's "Statewide Feasibility of a Potential New York State Biodiesel Industry" report (LECG et al. 2003) to develop a simple production model (for a more detailed discussion of the production model please refer to Appendix L: Selected Future Production Pathways in New York). For the NYC metropolitan area an assumption was made that 90% of the yellow grease produced could be used for biodiesel production. Nevertheless, away from this densely populated area it is difficult to make assumptions about the percentage of yellow grease that could be available for biodiesel production, due to variables such as location of rendering plants and the economic feasibility of collection in more rural areas. Based on population density for 2006 from the NYS

Department of Health, the remaining counties were divided into categories and were assumed to have the following recovery rates: metro/suburban (80% capture), suburban/rural (70% capture), rural (60% capture), and mountain (50% capture). Hamilton County is estimated to produce considerably less yellow grease than any other, so it was estimated to have a capture value of 0%. Based on these assumptions, it was calculated that of the total 180million lbs of yellow grease produced within New York State, an estimated 150million lbs would be available for biodiesel production. In reality the amount of yellow grease captured for biodiesel production in a central facility will depend largely on the location of collection and rendering facilities, and the location of a biodiesel production facility itself.

Additional data used as inputs for the model follow:

- Total annual potential l yellow grease production in New York State was 180,000,000 pounds (LECG et al. 2003)
- Yellow grease production estimated at 9.32pounds per capita (LECG et al. 2003)
- As of August 7, 2009, the cost of yellow grease from renderer to biodiesel producer was $0.225/pound (Jacobsen, 2009)

Exhibit A

Case Studies	**OCRRA**	**NEST**	**NYSDEC**	**NYC**	**EPA**
tons MSW evaluated	6.8	427,529	29,700,000	2,755,804	254,000,000
tons biomass	3.2	252,169	17,523,000	1,401,602	161,544,000
% of MSW is waste biomass	47.06%	59%	59%	50.86%	63.60%
tons waste biomass recyclable	N/A	88,998	N/A	413,371	68,230,000
% waste biomass recyclable	N/A	35.29%	N/A	15%	42.24%
tons biomass available for ethanol	N/A	163,171	N/A	988,231	93,314,000
% of waste biomass available for ethanol	N/A	65%	N/A	71%	57.76%
% of total MSW available for ethanol	N/A	38%	N/A	35.86%	36.74%
tons paper waste	N/A	142,492	11,583,000	642,654	83,010,000
% of MSW is paper waste	N/A	37.3%	39%	23.32%	32.68%
tons of paper waste recoverable	N/A	58,304	N/A	413,371	N/A
% of paper waste recoverable	N/A	40.9%	N/A	64.32%	N/A
tons woody waste	N/A	19,008	N/A	27,558	14,210,000
% of MSW is woody waste	N/A	5.00%	N/A	1%	5.59%
tons woody waste recovered	N/A	846	N/A	N/A	N/A
% of woody waste recovered	N/A	4.45%	N/A	N/A	N/A
tons food waste	N/A	37,824	3,267,000	589,742	31,650,000
% of MSW is food waste	N/A	9.90%	11%	21.40%	12.46%
tons food waste recovered	N/A	436	N/A	N/A	N/A
% of food waste recovered	N/A	1.15%	N/A	N/A	N/A
tons yard waste	N/A	52,845	2,673,000	141,648	32,630,000
% of MSW is yard waste	N/A	13.80%	9%	5.14%	12.85%
tons of yard waste recovered	N/A	29,412	N/A	N/A	N/A
% of yard waste recovered	N/A	55.66%	N/A	N/A	N/A
tons other waste	N/A	175,360	N/A	1,354,202	92,456,000

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