Tompkins County Energy Road Map

Neyvin De Leon

MEng in Mechanical Engineering

Cornell University Class of 2011

Email: njd55@cornell.edu Date: 5/21/2012

Advisor: Professor Zellman Warhaft

Table of Contents

Executive Summary

The biomass production potential of Tompkins County is analyzed and determined to be large enough to meet a significant portion of the region's heating needs; 80,006 tons of woody biomass can be produced per year, enough to heat 45% of the homes in the County. Additionally, the amount of land available for biomass harvesting is estimated to be 11,460 acres at the present time, and is expected reach 25,958 acres by 2020 due to improvements in agriculture technology.

Although state-wide guidelines and best management practices have not yet been developed for forest biomass harvesting, initial guidelines have been developed at the County level. While such guidelines are in development, it is recommended for officials to promote the harvesting of dedicated biomass crops of cool season grasses. Although not the cheapest of options, growing such crops poses a smaller threat to the environment than harvesting woody biomass without the proper guidelines in place. Through interviews with local experts, such cool season grass fields are found to produce about 5 tons of material per acre per year. On the other hand, agricultural by-products, especifically corn stover, is not present in large enough quantities throughout the County to serve as a significant source of energy.

Introduction

Tompkins County has several renewable sources of energy it could use to lessen its dependence on coal and reduce its carbon footprint. The Tompkins County Energy Road Map is an effort to quantify such potential. This report focuses, in particular, on the use of locally-sourced biomass for heat generation purposes.

For this project, satellite images of the County's towns, generated through Google Earth, were analyzed to provide an estimate of the amount of land available for bio-energy crop harvesting. The images were then processed using a Matlab program and then compared with the results of interviews conducted in 2006 with local land owners. The results of such comparisons and the workings of the image processing tool used are discussed in detail.

Also covered in this report are the County's most viable options for processing the biomass it may generate. These include directly combusting biomass using wood stoves, gasifiers, and wood-fired space heaters, cofiring within AES Cayuga, a coal-powered plant, and finally, extracting syngas from the biomass for subsequent combustion in Cornell's gas-powered plant.

In order to provide rapport for the options presented herein, interviews with professionals in the areas of biomass combustion, syngas production, and plant genetics were conducted and their opinions recorded. These individuals are all Cornell faculty and include Perrine Pepiot and Elizabeth Fisher, both from the Mechanical and Aerospace Engineering Department, Lawrence Smart and Hilary Mayton, from the Plant Breeding and Genetics Department, and Peter Woodbury, from the Department of Crop and Soil Sciences.

It must be kept under consideration that burning biomass produces zero net output of greenhouse gases, aside from the carbon emitted to harvest and process it. This is attributed to the fact that the CO2 that is released was previously part of the atmosphere. Fossil fuels, on the contrary, release gases that have been out of the carbon cycle for millions of years. With this in mind, herein lies the case for biomass utilization in Tompkins County.

Potential for County-Wide Biomass Production

The most fundamental resource for this project is land base. Thus, this study began by investigating the current division of land in the region of interest. With a total area of 305,368 acres, Tompkins County can be divided into forested areas, agricultural fields, brushland, and urbanized areas, among others, not fit for biomass harvesting. This final category was labeled as "other". Below is the breakdown of the land in the County. Agricultural land includes field crops and land used for livestock production. Forested land includes both private and state-owned forests.

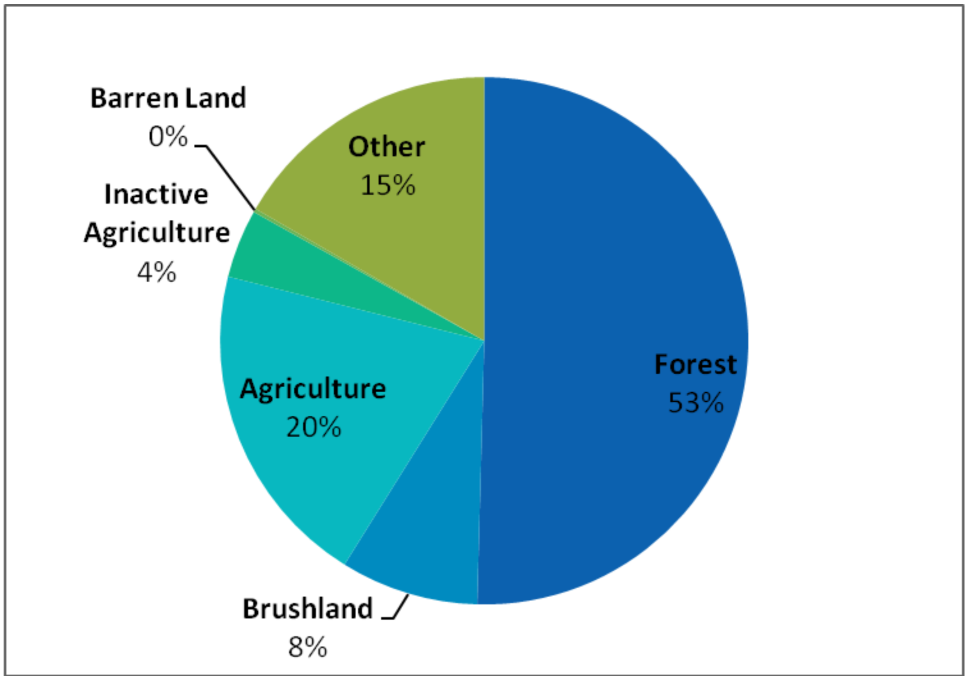


Figure 1: Land Distribution in Tompkins County. Department of Planning, 2007

The chart above is based on the 2007 Tompkins County Land Use and Land Cover project performed by the Department of Planning. The project processed high resolution orthoimagery acquired from the NYS Office of Cyber Security and Critical Infrastructure Coordination, CSCIC. As a whole, in 2007, the County contained 66,400 acres of active agricultural land, 13,926 acres of inactive agricultural land, 167,277 acres of forested land, and 28,075 acres of brushland. For the purpose of biomass harvesting, one of the most attractive portions of land are those labeled as inactive agriculture. However, such fields, although not in use, are not necessarily available for biomass cultivation.

In 2006, the Cornell Cooperative Extension interviewed 380 land owners in Tompkins County and investigated their willingness to allow biomass harvesting on their unused fields [1]. The study found that about 50% of those interviewed viewed the practice positively and were willing to allow it on their land. Assuming the recorded responses to be representative of the views of all owners of inactive agricultural fields in the County, in 2007 there were 6,963 acres (50% of the total) of land of such type available for biomass production. Such figure is expected to increase in the coming decades.

Peter Woodbury, a local expert in Crop and Soil Sciences, believes that new developments in fertilizer technology and land use management will translate into smaller land requirements per unit mass of food produced. In his 2011 report, Dr. Woodbury argues that the newly available land could then be used to produce biomass without impacting local food production. He performed this work while quantifying the production potential of various sources of biomass in the State as part of the Renewable Fuels Roadmap and Sustainable Biomass Feedstock Supply for New York. Below are the project's land area estimates for Tompkins County [3].

Table 1: Land Expected to be Available by 2020 for Biomass Harvesting. Forests are not considered. Woodbury 2011 [3]. 1 ton=2,000 lbs. 1 sq mile=640 acres

Crop Land (acres)	**Hay Land** (acres)	**Grassland** (acres)	**Shrubland** (acres)	**Total Area** (acres)	**Production** (dry tons/ year)	**Yield** (tons/acre/year)
11,719	2,084	7,243	4,911	25,958	115,682	4.5

After analyzing historical trends in productivity, Woodbury estimates that a total of 13,803 acres of land currently used for food production will be available for biomass production by 2020. This figure is the sum of crop land and hay land area shown above and represents more than twice the inactive agriculture land available in 2007. Taking into account grassland and shrubland available at the present time, 25,958 of acres of land will be available for biomass production by 2020. Thus, land area estimates are available for 2007 and 2020, but not for 2012.

The following computer program was developed in order to provide an estimate of the land currently available for biomass harvesting, thereby bridging the gap between the estimate presented by Woodbury and that resulting from interviews with local land owners. The data used for the program was obtained from the Biomass Resource Mapping Workshop, performed by the Cornell Cooperative Extension. The workshop produced maps highlighting the location and private unused fields potentially available for biomass harvesting. The program created as part of this project was then used to estimate the total area occupied by such fields.

The Biomass Resource Workshop produced maps of three townships, Danby, Dryden, and Ulysses, and highlighted the activity for which each portion of land was being used.The program, whose interface is shown on the following page, is able to accept these maps and tell the user what portion of the image a certain type of land occupies.

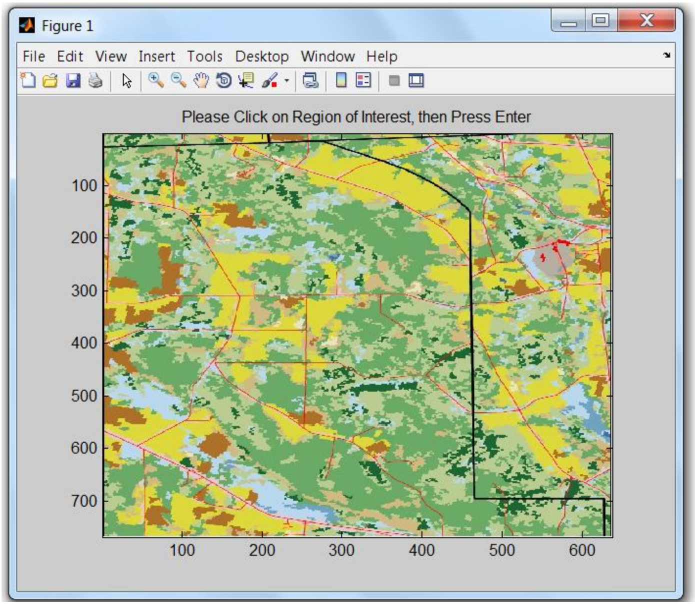


Figure 2: Program User Interface. Program allows users to input an image and select the area of interest. The image must be color coded. In this case, brown represents land available for biomass harvesting. Green represents forests.

The sections of land in the images used were demarcated using various colors prior to being used. Areas in brown represent lands available for biomass production. Such areas are composed of inactive agricutltural fields, brushland, and forestland. The percent compositions determined with the program were recorded and used along with the area represented by each image to obtain an estimate of the land available for biomass production. The program's actual code can be found attached to this report. After analyzing the percent composition of the townships in Tompkins County, the program was used to help estimate that about 11,460 acres are currently available for biomass production.

The main shortcoming of the project upon which this analysis is based is that it was not carried out for all the townships in the County. Thus, the data was extrapolated to provide an estimate for the regions for which no data was available; the average percent of available land for the towns of Danby, Dryden, and Ulysses was calculated and assumed to apply to the rest of the towns.

Table 2: Percent of Land Available for Biomass Harvesting by Township. Cornell Cooperative Extension 2009.

Township	Percent Available	Area (Acres)	Land Available (Acres)
Danby NE	7.2	877	63
Danby NW	10.4	1278	133
Danby SE	8.4	948	80
Danby SW	3.1	282	9
Dryden NE	16.5	3331	550

Dryden NW	8.4	1701	143
Dryden SE	8.7	1728	150
Dryden SW	8.4	1978	166
Ulysses NE	12.6	505	64
Ulysses NW	22.7	1821	413
Ulysses SE	22.8	1830	417
Ulysses SW	21.5	1722	370
Caroline	12.6	16510	2080
Newfield	12.6	14218	1791
Enfield	12.6	9019	1136
Groton	12.6	15024	1893
Lansing	12.6	12375	1559
Ithaca	12.6	3520	444
Total			**11,460**

Woody Biomass Utilization

After determining the land composition in the County, the next step consisted of analyzing the yield rates of different types of crop. This analysis would then help determine the most appropriate biomass crop for the region. Below are Professor Woodbury's estimated yields for three types of biomass crops that can be grown in the County. In this table, 115,682 tons of dry material that could be produced on hay, grass, and shrub lands throughout the region are added to those obtained from local forests and agricultural residue. In total, 206,976 dry tons can be produced per year.

Table 3: Biomass Yield Rates for Tompkins County. Woodbury 2011.

Wood Chips from Existing Forests (dry tons/year)	**Dedicated Energy Crops** (dry tons/year)	**Corn Stover** (dry tons/year)	**Total Biomass** (dry tons/year)
87,006	115,682	4,288	206,976

The study found that 87,006 tons of wood chips could be extracted sustainably from forests in the region. In order to gain an appreciation for the amount of energy this represents, such figure can be compare with the amount of coal used by AES Cayuga in a year. Dried wood has an energy content of about 19 MJ/Kg, or 7,896 Btu/lb. By comparison, Bituminous coal has an energy content of 30 MJ/Kg. AES Cayuga burns 860,000 tons of coal per year [8]. Thus, the amount of wood that could be sourced from the County's local forests is equivalent in energy content to about 6.4% of the coal used by the region's main power plant. This estimate can be made more accurate by using the average heat content of wood typically found in the County. To this end, the following analysis uses data collected for the 2007 Tompkins County Forest Management Plan, which lists the abundance of the each of type of tree found on the 600 acres of County-owned forestland in the Towns of Newfield and Caroline. The heat and mass density are typical values for each tree species [4].

Table 4: Heat and Mass Densities for Wood Found in Tompkins County-owned Forest Properties. 1 Btu=1055.1 Joules. 1 chord=3.62 cubic meters

Wood Species	**% in Forests**	**Heat Density** (MMBTU/chord)	**Mass Density** (lb/chord)	**Heat Content** (BTU/lb)
Red Maple	5.74	18.7	2290	8166
Sugar Maple	4.5	24	2120	11321
White Ash	3.03	23.6	2240	10536
Black Cherry	1.4	20	2670	7491
Northern Red Oak	1.26	24	3690	6504
Hemlock	8.94	15.9	3100	5129
Black Birch	0.703	21.7	3200	6781
Beech wood	2.36	24	3120	7692
Quaking Aspen	3.16	14.7	3480	4224
Basswood	0.866	13.5	2870	4704
White Pine	5.45	14.3	4330	3303
Pitch Pine	1.1	17.1	3300	5182
Black Locust	4.27	27.3	3240	8426
Scots Pine	1.73	18.1	3250	5569
Hawthorn	2.32	19.1	4010	4763
Fire Cherry	4.66	20	3180	6289
Ironwood	7.56	26	3480	7471
Chestnut Oak	0.299	12.9	2870	4495
Hickory	0.849	27.7	4330	6397
Red Spruce	21.4	16	3300	4848
Service Berry	1.42	17.4	3240	5370
Tamarack	2.47	20.8	3250	6400
White Oak	0.402	25.7	4010	6409
Yellow Birch	3.14	21.7	3180	6824
Average				**6429**

The average heat content for wood present in the County was found by performing a weighted average on the abundance and heat content of each type of wood listed above. From an environmental standpoint, it is preferable to burn wood over coal; the latter produces soot along with mercury, a poisonous heavy metal. If the type of wood is carefully chosen, sulfur dioxide emissions can be reduced. The option of replacing part of the coal feed with wood, a process known co-firing, will be discussed in Appendix 1. A more easily-implemented option for the region is using such woody material for heating homes.

Domestic Heating using Wood

According to the Tompkins County Department of Planning's 2008 Community Greenhouse Gas Emission Inventory, the energy required to heat and light residences in Tompkins County was 3,396,123 MMBtu. Of that, 1,001,266 MMBtu was from electricity use in the residential sector. If we assume that 10% of housing units are heated using electricity, that amounts to 100,127 MMBtu. Heating with oil constitutes 247,425 MMBtu, natural gas, 1,701,883, and propane, 445,549. In total, this amounts to a 2,494,984 MMBtu demand to heat the residential sector.

Additionally, according to the 2010 Census, there were 41,674 housing units in Tompkins County. Dividing 2,494,984 MMBtu by 41,674 yields an average use of 59.87 MMBtu per year per housing unit. Assuming the heat content of wood determined above, 6429 Btu/lb, and Woodbury's estimated woody biomass production potential for the County of 87,006 tons, then 18,685 homes could be heated using locally sourced wood. Such figure constitutes 44% of housing units in Tompkins County.

One common argument against the use of wood is that it releases more CO_2 per unit of energy produced than fossil fuels. Home heating oil produces .26 Kg of CO_2 per KWh. Natural gas, on the other hand, produces .23 Kg of CO_2 per KWh, and finally, the combustion of wood releases .39 Kg of CO_2 per KWh [4]. Thus, alhough such claims are correct in an immediate sense, it must be kept in mind that woody material left to decompose in forests would have released the same amount of carbon dioxide, albeit over a longer period of time. Thus, burning wood instead of fossil fuels represents a net saving in carbon emissions.

Aside from considerations of greenhouse gas emission, another important issue that must be addressed is the release of pollutants such as particulate matter and sulfur dioxide. According to the Environmental Protection Agency, EPA, wood contains less pollutants than coal per unit mass; oak wood is .09% sulfur and treated lumber (pine) is .005% sulfur. Each have negligible amounts of chlorine. For comparison, bituminous coal is 1.87% sulfur and .06% chlorine [5]. Modern-day coal plants avoid releasing sulfur into the atmosphere via the use of flue gas desulfurization. Such technology can remove an excess of 95% of the sulfur contained in the combustion products of coal, which leaves the containing .09% sulfur [6]. Evidently, the amount of sulfur produced by burning wood is equal or less than that produced by the typical coal plant, depending on the type of wood used.

Best Management Practices for Forest Biomass Harvest

Woody biomass extraction, if done incorrectly, can have a significant impact on local ecosystems. Such impact may be mitigated by following what are known as best management practices. These specify standard operating procedures such as the frequency and scale at which woody debris can be extracted and living trees may be fallen. Unfortunately, "New York currently has no immediate plans to develop biomass harvesting guidelines." [7]. Nonetheless, initial guidelines for local sustainable forest management have been created for Tompkins County. In 2007, Bevan Foresty created the Tompkins County Forest Management Plan in conformance with Forest Stewardship Council Guidelines [9]. This report contains harvesting guideline aimed at protecting water quality, soil conditions, and local wildlife. Some of the recommendations made by the report include harvesting while the soil is firm in order to minimize compacting and erosion. Additionally, a third of the harvest residue, including tree tops and branches, should be left on site to improve nutrient cycling. This residue should be distributed throughout the harvest area. The management plan also recommends creating a harvesting plan and carrying out a survey of the forest in question in order to quantify the number of endangered species present, unusual geologic features, and the amount of old or large trees.

Perennial and Warm Season Grasses for Heat Production

Perennial and warm season grasses can also be used domestically for heat production. The material extracted from such processes, after being adequately dried, can be mechanically processed into pellets, which can then be used within specially designed pellet boilers. These grasses can be harvested within the County's unused fields and brushland investigated previously. As with any type of crop, yield rate is an important concern with harvesting grasses for biomass.

Hilary Mayton, a Cornell professor, is currently studying the growth rate of several types of grasses in our region. During an interview, Mayton revealed that perennial grasses, such as switchgrass or Miscanthus, can yield about 10-20 tons per acre on a annual basis. After drying, this value decreases to 5 tons. Harvesting for this crop can be carried out in the fall. However, the main issue with these grasses is that they become productive three years after being planted, which further increases capital expenses.

On the other hand, cool season grasses can mature in the span of one year, leading to reduced labor costs. The main problem presented by cool seasons grasses, especially canary grass, is that they produce high levels of chlorine, sulfur, and ash when combusted. These pollutants may be reduced by strategically selecting the type of soil and fertilizer to use. Chlorine content in crops is typically attributed to the use of potassium chloride fertilizer. Silica content, which leads to ash formation, may be reduced by growing grass biomass on sandy soil. Finally, nitrogen concentration may be minimized by harvesting mature or overwintered forage.

Despite the many benefits of growing grasses for biomass, this is not the most economically feasible option. As an alternative, unused fields, such as brushland, can be harvested ,albeit with lower yields. Mayton estimates that unused fields can produce 1-2 tons of dry biomass per acre per year. She believes that collecting agricultural residue may be the best option for biomass utilization, from an economic point of view.

Agricultural By-products as Sources of Energy

Agricultural by-products or residues include undesired harvested material such as straw, husks, stalks, and leaves. Instead of discarding this material, it could be used for heat generation purposes. In New York State, the most significant are corn husks and small-grain straw. The latter, however, is highly prized for farm applications and thus not readily available as a source of energy. Corn husks, on the other hand, is not as valued and is only used to reduce erosion and return nutrients to the soil. As a conservative measure, Professor Woodbury suggests using 12.5% of the corn stover produced after a given harvest. Taking 12.5% of the county's corn stover yield rate listed in table 1 results in 536 dry tons per year. Assuming a caloric value of 14 Million Btu per ton [10], locally generated corn stover can provide enough energy to heat 93 homes. Given the small yield rate of corn stover in Tompkins County, it does not appear to be a viable source of energy in the long term. However, it can be used to test the willingness of the public to meet their heating needs using biomass.

Conclusions

Tompkins County currently has about 11,460 acres of land available for biomass production, up from 6,963 acres in 2007. This figure is expected to grow to 25,958 acres by 2020. The current productivity of such lands has been estimated to be 80,006 tons of woody biomass per year. This yield rate is enough to heat 45% of the homes in the County, assuming a heat content of 6,429 Btu/lb. Although state-wide guidelines and best management practices have not yet been developed for biomass harvesting, initial guidelines have been developed at the County level. Growing dedicated biomass crops such as perennial and warm season grasses, although not the cheapest of all options, poses a smaller threat to the environment and eliminates the need to develop best management practices. Such fields can produce about 5 tons of material per acre per year. Agricultural by-products, especifically corn stover, is not present in large enough quantities throughout the County to serve as a significant source of energy.

Recommendations

Based on the analysis presented above, the County should begin utilizing biomass by harvesting cool season grasses, such as canary grass, within unused agricultural fields. Initially, such practice should be performed at a small scale, on the order of 10 acres. Such small scale will be less resource intensive and can serve as a pilot program that can provide an estimate of the local demand for biomass as a source of heat in the region. Such a scheme will require machinery to dry the material and compress it into pellets which can then be combusted within wood stoves or similar technologies. While this evaluation of biomass demand in the region is taking place, more formal guidelines to harvest woody biomass from local forests should be developed. The availability of woody biomass will ensure a constant supply of biomass even throughout the growing season of perennial grasses. Once large scale harvesting of biomass has been proven feasible within Tompkins County, co-firing may be considered as option to reduce the carbon emissions of AES Cayuga, as explained in Appendix 1.

References

[1] Young, Robert F. *Vision for Tompkins County Sustainable Enterprises*. Rep. Ithaca, 2006. Print.

[2] Haytar, Shayla, and Stephanie Tanner. "Biomass Cofiring in Coal-Fired Boilers." Federal Energy Management Program, 5 May 2004. Web. 21 Jan. 2012. <http://www1.eere.energy.gov/femp/>.

[3] Woodbury, Peter. "Renewable Fuels Roadmap." *Renewable Fuels Roadmap*. New York State Energy Research and Development Authority. Web. 21 May 2012. <http://www.nyserda.ny.gov/Publications/Research-and-Development/Biomass-Solar-Wind/Renewable-Fuels-Roadmap.aspx>.

[4] "Combustion Fuels - Carbon Dioxide Emission." *Combustion Fuels - Carbon Dioxide Emission*. Engineering Toolbox. Web. 08 May 2012. <http://www.engineeringtoolbox.com/co2-emission-fuels-d_1085.html>.

[5] "Characterization of Emission From The Combustion of Wood and Alternative Fuels in a Residential Woodstove." *National Service Center for Environmental Publications (NSCEP)*. Environmental Protection Agency. Web. 09 May 2012. <http://nepis.epa.gov/Exe/ZyNET.exe/9100RMOK.txt?ZyActionD=ZyDocument>.

[6] Cooper, C.D. "Air Pollution Control Technology Fact Sheet." *United States Environmental Protection Agency* (2002). Web. 9 May 2012.

[7] Evans, Alexander M., and Robert T. Perschel. "Assessment of Biomass Harvesting and Retention Guidelines." *Forest Guild* (2010). Apr. 2010. Web. May 2012.

[8] "Abstract." *AES Cayuga Coal Plant NY USA*. Web. 10 May 2012. <http://globalenergyobservatory.org/geoid/13>.

[9] "Tompkins County Forest Management Plan." Tompkins County Department of Planning, 10 Oct. 2007. Web. May 2012.

[10] "Heating Values of Hydrogren and Fuels." Essom Co. Web. <http://www.essom.com/backend/data-file/engineer/engin21_1.pdf>.

Appendix 1: Cofiring in AES Cayuga

Cofiring, the simultaneous combustion of two different types of fuel, can be employed locally in the AES Cayuga plant in order to reduce greenhouse emissions and pollutants. This is a proven method that has been installed in various federally-owned plants in the nation. According to the Federal Energy Management Program, "biomass can substitute up to 20% of the coal used in the boiler".

Generally, cofiring does not affect the efficiency of a boiler, thus the plant's energy output will remain unchanged. According to FEMP waste wood and waste paper are usually the most economical sources from which to provide fuel for cofiring. However, these are not viable sources of fuel for our community.

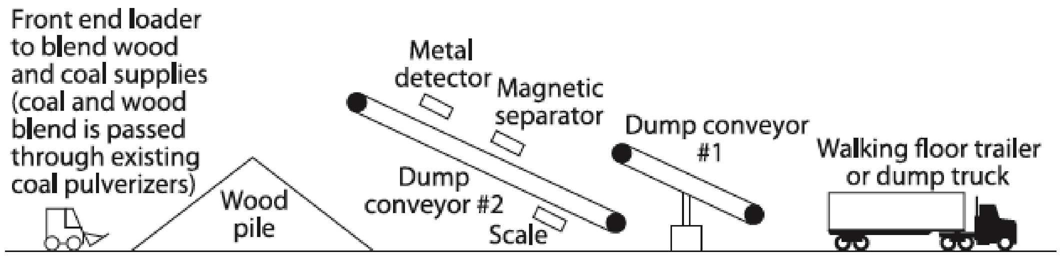
In 2006, the Tompkins County Solid Waste Management Division handled 11,310 tons of paper. As was previously mentioned, AES Cayuga consumes 860,000 tons of coal/year. Thus, we can only replace 1% of the coal with waste paper (assuming a heat content of 7500 BTU per pound for waste paper). Although waste paper could be sourced from other Counties, this would further decrease our energy independence. Instead, biomass crops can be grown and processed within Tompkins County.

Miscanthus Giganteus, a cold resistant perennial grass, can yield 1000 kg per acre on an annual basis. 1 ton of the plant is equivalent in energy to .5 tons of coal, considering 15% water content. Additionally, the grass can provide 2.9MJ of energy per acre. Thus, we would need to grow Miscanthus in about 22 acres of land to replace 20% of AES Cayuga's coal consumption. This was calculated using data from Miscanthus grown in Illinois, which has climate similar to that of our region.

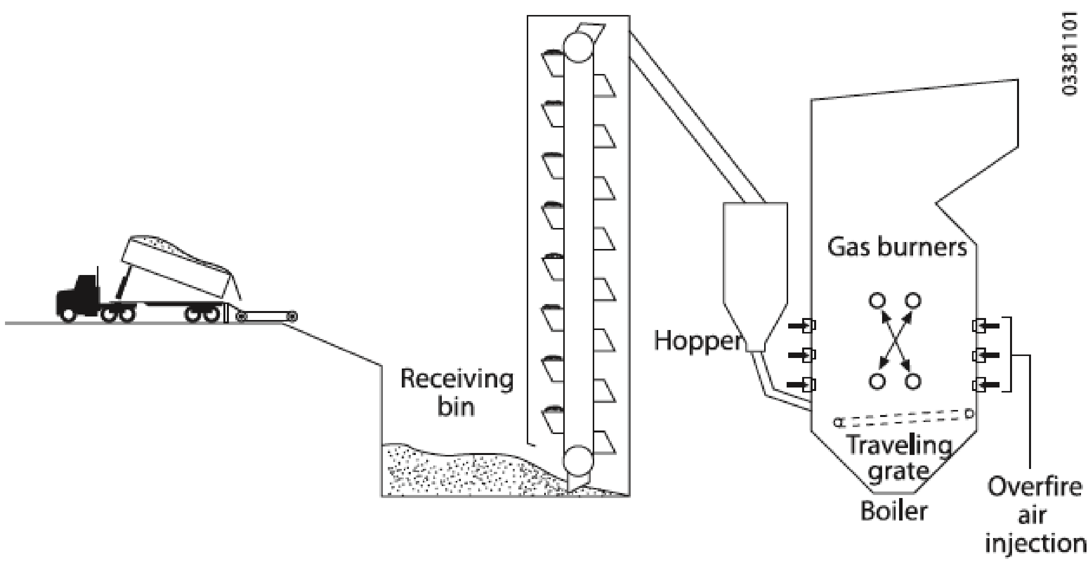
Cofiring will decrease mercury emission, as less coal will be burnt. Additionally, lower levels of sulfur will be emitted. The plant produces most of its energy from bituminous coal and emits 2,700 Tonnes of SOx per year. This value can be reduced to 2,200 Tonnes per year through cofiring. One issue with cofiring is that it will result in the release of greater amounts of volatile organic compounds, VOCs.

Perrine Pepiot, a Professor at Cornell University and an expert in biomass conversion processes, believes cofiring presents an important opportunity to reduce carbon emissions in the region. Pepiot also expressed that the increase in VOCs emission is a small price to pay considering the many benefits cofiring offers. Finally, Professor Pepiot suggested that her main concern with the technology was financing the building of equipment that could deliver biomass particles of the proper size and at a fast enough rate. "In a typical burner, coal is pulverized before being combusted. Given the fibrous nature of cellulosic biomass, it is very hard to grind the material to a small enough size to match that of the pulverized coal." The cost of retrofitting the AES plant and supplying the fuel are amongst the most significant for cofiring. The contributions to such cost are analyzed in detail below.

Below is a diagram depicting the setup that is usually used in cofiring. Similar conveyor belts are currently being used in AES Cayuga to transport coal. The use of trucks may be eliminated if the biomass-producing fields are situated close enough to the rails that the AES plant uses to deliver coal to its plant.



After the biomass product is delivered to the receiving bin, a hopper grinds it to a size comparable to that of pulverized coal.



The costs of typical cofiring plant-retrofitting processes are listed below. For comparison purposes, the AES plant outputs 320MW of power and uses pulverized coal.

Boiler Type	Example Plant Size (MW)	Heat from Biomass (%)	Biomass Power (MW)	Unit Cost ($/kW)[1]	Total Cost for Cofiring Retrofit ($)	Net Annual Cost Savings ($/yr)[2]	Payback Period (years)	Production Cost, no Cofiring (¢/kWh)[3]	Production Cost, with Cofiring (¢/kWh)[3]
Stoker (low cost)	15	20	3.0	50	150,000	199,760	0.8	5.25	5.03
Stoker (high cost)	15	20	3.0	350	1,050,000	199,760	5.3	5.25	5.03
Fluidized bed	15	15	2.3	50	112,500	149,468	0.8	5.41	5.24
Pulverized coal	100	3	3.0	100	300,000	140,184	2.1	3.26	3.24
Pulverized coal	100	15	15.0	230	3,450,000	700,922	4.9	3.26	3.15

According to FEMP, biomass fuel supplies "should cost at least 20% less, on a thermal basis, than coal supplies before a cofiring project can be economically attractive" [2]. Otherwise, the facility will need to sell its electricity at a higher cost. Northern Appalachian Bituminous coal sold for $70/ton in 2011. In comparison, the chart below shows that the annual cost of growing and processing Miscanthus totals $423 per acre. 22 acres are needed to produce enough Miscanthus as to replace 20% of AES Cayuga's coal requirements. This amounts to $9310 per year, or $50 per ton of biomass produced. We must keep in mind that this analysis does not include the cost of retrofitting the coal plant.

Aside from the initial cost of the retrofitting process, an important point that must be kept in mind is the predicted variability in the supply of biomass. If constant supply rates are not maintained, the plant will experience what is known as cycling -a fluctuation in boiler temperatures and consequently, power output. Fluctuating temperatures create thermal stress on metal components, increasing wear and maintenance costs in the long term.

Appendix 2: Combusting Syngas in Gas-Powered Plants

Although cofiring provides a great way to reduce carbon emissions in the long term, the County must completely abandon the burning of coal if it is to reduce its carbon emissions to 20% of 2005 levels by 2050. The next logical step is to convert AES Cayuga into natural gas-powered plant, just as was done with Cornell's power plant. In order to keep the biomass-producing capabilities from going to waste, the County can resort to burning syngas in gas turbines. The syngas could be extracted through pyrolysis from the same Miscanthus crops that were developed for cofiring. In this case, a slightly larger area would need to be developed in order to account for the energy used during pyrolysis.

Appendix 3: Matlab Program Used to Process Satellite Images

```
function mapsizing(imagename)

%This program helps the user quantify the total portion of an image that
%has the specified color of interest. The output will be in the form of a
%percentage. The program is not able to determine the scale of the an
%image. This trivial calculation is left to the user.

%Reads image of interest and stores it in a matrix
image=imread(imagename);
imagesc(image);             %displays pre-processed image
title('Please Click on Region of Interest, then Press Enter')
[x,y]=ginput;               %Asks user to choose a point
x=round(x);
y=round(y);
imfinfo(imagename);         %remove semicolon to view image details


%Determines color composition of image of interest
red=image(x,y,1);                   %amount of red in pixel
green=image(x,y,2);                 %amount of green in pixel
blue=image(x,y,3);                  %amount of blue in pixel
[rows,columns,layers]=size(image);  %dimensions of image in pixels
totalpixels=(rows*columns)*layers;  %total number of pixel
keycolor=0;


%quantifies # of mathches between color of interest and image
for i=1:rows
    for j=1:columns
           redlayerdiff=abs(image(i,j,1)-red);
           greenlayerdiff=abs(image(i,j,2)-green);
           bluelayerdiff=abs(image(i,j,3)-blue);
           if redlayerdiff<6 && greenlayerdiff<6 && bluelayerdiff<6
            keycolor=keycolor+1;
           end
    end
end

percentage=keycolor*100/totalpixels;
percentage=num2str(percentage);
fprintf('The Type of Land of Interest Occupies ')
fprintf(percentage)
fprintf(' percent of the Map')
```