Biomass Potential

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Executive Summary

Total Potential

Energy Source	Heating (MMBtu/yr)	Percent of Total 2008 Heating Demand
Biomass Energy Potential	**4,518,037**	**87%**
2008 Community Demand	*5,208,990*	

Major Assumptions

	Land Suitable for Woody Biomass	**Land Suitable for Dedicated Energy Crops**	**Land Suitable for Waste Agricultural Products**
Types of Biomass	Cordwood, wood pellets, wood chips	Wild or fallow-field grasses, switchgrass, reed canary grass, etc.	Corn stover, other agricultural waste products from forage-land
Land Included	"Forests" in 2012 Land Use Land Cover Analysis	"Grassland", "Brushland", "Inactive Ag" in 2012 Land Use Land Cover Analysis	"Active Ag" in 2012 Census of Agriculture, Tompkins County
Land Excluded	Unique natural areas (UNAs), slopes >15%, 100' buffers both sides intermittent and perennial streams and roads, and parcels <10 acres	UNAs, slopes >15%, 100' buffers both sides intermittent and perennial streams and roads, and parcels <10 acres	No land classified as Active Agricultural lands were excluded
Harvest Rate	1 cord/acre/year can be sustainably harvested according to "Forests of NY" 2013 USDA report	Switchgrass yields 3-8 dry tons/acre/year; used 5 dry tons/acre/year for analysis	2012 Census of Ag's "Top Crops Grown in Tompkins County." NY corn yields 130-150 bu/ac, 42 bu corn grain produces 1 dry ton of stover, so 3 dry tons of stover/acre. Forage-land low-quality hay yields 1.7 ton/ac yields 27,737 tons/yr
Heat Value of Biomass	12.9 MMBtu/ton based on the heat density in dry wood in County-owned forestlands, 2007	15.5–16.5 MMBtu/ton heat value for Switchgrass	15.5 MMBtu/ton heat value for corn stover and 15 MMBtu/ton for hay
Sequestration	Discussed but not quantified for potential	Discussed but not quantified for potential	Discussed but not quantified for potential

Biomass is an important part of the energy sector, with significant growth potential to decrease our use of fossil fuels, particularly for space heating. As such, biomass utilization has many benefits over fossil fuels, as well as some other advantages over other renewable energy technologies.

The main objective of this section is to evaluate the potential at both the supply and demand sides of the utilization of biomass for residential and commercial space heating in Tompkins County, as well as provide a discussion of the various types of available combustion technologies. Biomass can also be used effectively for certain types of process heating, and even space *cooling*, but these are not included in this analysis.

Lands that can produce biomass resources include 1) Forests, 2) Inactive Agricultural Lands, Brushland and Grassland, and 3) Active Agricultural Lands. Forests can provide cordwood, wood pellets, and wood chips. Inactive Agricultural Lands, Brushland and Grassland can supply wild or fallow-field grasses and can be planted in dedicated energy crops such as switchgrass, reed canary grass, etc. Active Agricultural Lands can provide agricultural residues such as corn stover and other agricultural waste products.

As will be discussed, while significant work has been done to quantify the gross potential for growing and harvesting agricultural biomass from Active and Inactive Agricultural Lands, Brushland and Grassland, the combustion equipment for utilizing this resource is less evolved than that for woody biomass. Therefore, this report separates out the potential for woody biomass from that of dedicated energy crops to meet some portion of the community's energy needs. Based on current trends, however, we expect that the efficient combustion of agricultural biomass (growing and processing, as well as combustion equipment) will be significantly more mature within the next 10 years, allowing this feedstock to become a major energy source within the timeline of this roadmap.

Our analysis of the biomass production potential in the county reveals the following results:
Woody Biomass from Forests:

- Applying constraints such as the physical ability to harvest, we estimate there are roughly 69,775 acres of forested land available for woody biomass harvest.
- With a yield of roughly one cord per acre per year that can be sustainably harvested (and about 2.5–3 green tons, or 1.5 dry tons/cord), this results in roughly 104,663 dry tons of woody biomass being available for harvest annually in the county.
- Based on the heat value of that wood, forests in the county could yield roughly 1,345,751 MMBtu/year of thermal energy on a renewable basis.

Energy Crops on Inactive Agricultural Lands, Brushlands and Grasslands:

- Our analysis shows that Tompkins County has roughly 29,668 acres of inactive agricultural, brush and grass lands that could potentially be available for dedicated energy crop harvest.
- Growing dedicated energy crops, such as switchgrass, on inactive agricultural, brush and grass lands within the county could provide roughly 148,340 tons of biomass each year for 2,373,440 MMBtu/year.

Active Agricultural Lands:

- Waste residues from active agricultural lands (e.g., corn stover), while currently not utilized to any great degree, have the potential to become significant sources of energy.
- This sector has the greatest potential for growth in terms of what materials can be utilized and the combustion equipment that can handle it.
- Active agricultural land in the county totals 43,547 acres. Applying appropriate constraints, this can provide roughly 798,846 MMBtu/year.

Table 1. Total Biomass Energy Potential in Tompkins County

Type of Biomass	Land Cover Category	Total Acreage	Suitable Acreage	Yield (tons) †	MMBtu/yr‡
Wood	Forest	141,056	69,775	104,663	1,345,751
Energy Crop	Brushland	27,431	15,304	76,520	1,224,320
	Grassland	11,938	6,822	34,110	545,760
	Inactive Ag	9,984	7,542	37,710	603,360
	Subtotal		29,668	148,340	2,373,440
Ag Waste	Active Ag	N/A	N/A	N/A	798,846
Total					4,518,037

Sources:†(1) USDA Forest Service, Forest Inventory and Analysis. 2012. (2) Sustainable Corn Stover Harvest. Ertl, D. Iowa Corn Promotion Board. 2013. (3) New York Crop and Livestock Reports for October 2012 and November 2013. USDA National Agricultural Statistics Service, New York Field Office.‡ (1) Fuel Value Calculator. Forest Products Laboratory. 2004. Available at www.fpl.fs.fed.us/documnts/techline/fuel-value-calculator.pdf. (2) Properties of Biomass, Appendix to Biomass Energy Fundamentals, EPRI Report TR-102107. Jenkins, B. 1993. Available at cta.ornl.gov/bedb/appendix_a/Heat_Content_Ranges_for_Various_Biomass_Fuels.xls.

In addition, an oft-overlooked resource, waste wood, could be used for heating facilities. The City of Ithaca, alone, currently removes approximately 100 tons of wood in the form of dead trees or other removals each year, which could easily be used to heat a facility.

Biomass thus represents an opportunity to significantly reduce the county's carbon emissions, while also providing several additional environmental and economic advantages over fossil fuels, as well as presenting some significant challenges.

Opportunities

- The region has ample woody biomass resources. Managing the region's forests for biomass in a sustainable and responsible way can not only increase forest productivity but lead to higher overall biodiversity, and, ultimately, healthier ecosystems. Biomass is considered a very low-carbon energy source, with an estimated <5% embodied energy in cordwood and <10% embodied energy in wood pellets, depending on how far they travel and, in the case of pellets, the source of the feedstock (most of the pellets produced regionally derive from mill waste).
- If properly managed, biomass derived from forests and non-crop agricultural lands can become not just a low-carbon fuel but create a net carbon-sequestering paradigm, since properly managed forests and fields are more productive at sequestering carbon than non-managed ones.[10]
- Utilizing the ample local rural resources creates and strengthens local jobs in forest management, harvesting, transportation, processing, etc., offers a source of income for rural landowners, and keeps money circulating within the region, further supporting and strengthening the community.
- Currently available combustion equipment, particularly on the large residential and commercial scale, is far better and cleaner-burning than what was available just a few years

ago. As interest in this type of equipment has increased, and fuel oil and propane costs have risen, more and more home and business owners are switching to biomass.

- Oil and propane delivery companies are starting to become interested in offering bulk delivery of biomass (usually in pellet form).

Challenges

- The greatest challenge with utilizing biomass for energy is controlling emissions. Much of the existing combustion equipment currently in use predates the 1990 EPA Phase II regulations governing wood stoves, as well as the EPA's early 2015 release of updated emissions regulations governing a much broader range of combustion equipment, including wood-burning cookstoves, pellet stoves, etc. However, since the early 1990s, there have been significant advances in the equipment itself, most importantly at the scale of residential and commercial boilers. Modern two-stage-combustion cordwood and pellet boilers have emissions that can be as low as those seen with oil- and propane-fired equipment. The challenge is educating sectors of the community who think about the older, more polluting equipment when they hear about heating with wood—making them aware of the existence of this equipment and helping homeowners make the transition.
- Biomass has less energy per volume than fossil fuels, requiring larger storage containers and/or more frequent deliveries. Because of this and the emissions concerns, significant expansion of biomass for space heating may not be appropriate in certain urban settings.
- Another challenge that utilizing biomass for energy faces is resistance to seeing our forests more actively managed. In large part, this is based on a lack of understanding about the current health of these forests and what sustainable, responsible forest management looks like. Because of a long history of mismanagement (or non-management) following a period of clear-cutting within the past hundred-or-so years, nearly all of the county's forestlands have grown up with a preponderance of non-native species in a situation analogous to a garden overrun with weeds. Because of this, simply leaving the forests to grow back "naturally" will not result in truly natural or healthy forests. In fact, biodiversity and overall forest health can be improved with greater forest management, which can include significant ongoing harvests of biomass. However, in order to avoid resistance, the public will have to be educated to this reality.
- The need to educate residents about the benefits of utilizing biomass for heating, and of the available technologies, is significant. The vast majority of forestland statewide is privately owned[17] and much of that forestland is found in relatively small family plots.

1. Introduction

In 2011, hydropower (4657 MW), wind (1403 MW), and biomass (512 MW) accounted for the greatest amount of renewable energy in New York State (NYS).[32] The state has 6.031 million tons of biomass resources, with potentially between 1 million and 1.68 million acres of non-forest land that can be used for bioenergy feedstock production.[33] Biomass resources include woody sources from forests, which currently contribute both cordwood, wood pellets and wood chips; woody sources derived primarily as waste from the lumber industry (wood pellets); agricultural byproducts such as corn stover and other agricultural waste; and dedicated energy crops such as switchgrass, miscanthus, and shrub willow, as well as wild or fallow-field grasses, that can grow on land not suitable for or otherwise not currently in agricultural production.

Current combustion technologies are able to handle a variety of biomass feedstocks—particularly different forms of woody biomass—with extremely low emissions and high efficiencies. The main forms of biomass for thermal applications are cordwood (used in wood stoves and boilers), pellets (used residentially and commercially in pellet stoves and boilers), and chips (used commercially in biomass boilers). (See *Combustion Technologies*, below, for more information.)

Figure 1. Cayuga Nature Center, in Ithaca, NY, has a 0.5 MMBtu wood chip-fired boiler (housed in a shipping container outdoors) that heats the main building, saving them about $15,000 each year on propane costs.

Pellets can be derived from forest products, agricultural residues, and dedicated energy crops. Currently, sawmills are the greatest source of wood chips and sawdust that make up the vast majority (>80%) of the raw material for wood pellets. The main local producer of wood chips is Wagner Lumber, based in Owego, which is also the largest local sawmill close to Tompkins County, actually managing three sawmills and one log yard. Wagner owns more than 3,000 acres of forestland and employs over 250 people. It is the largest manufacturer of hardwood lumber in the Northeastern United States, selling hardwood globally, with an annual total production of 60 million board feet. It is also the largest purchaser of hardwood logs in the Northeast.[47] Wood chips are a natural by-product of sawn lumber and represent 20% of the average saw log by volume. Sales of Wagner's wood chips are now being divided between medium-density fiberboard manufacturers, pulp and paper manufacturing operations, particleboard producers, and commercial biomass boilers (including the chip boilers at Cayuga Nature Center and the Town of Danby highway barn). In addition, Mesa Reduction, based in Auburn, NY, has been in the business of aggregating biomass feedstocks since 2000, and has been expanding into the delivery of wood chips to biomass boiler facilities for the past few years. (Mesa is also working on chip-drying systems, since one of the greatest challenges with wood chips is their high moisture content, which can result in increased emissions in much of the existing wood chip-fired heating equipment.)

Wood pellets are made mostly (~85 %+) from sawmill sawdust (every sawn log yields about 10% sawdust), which is typically kiln-dried, heated with steam under pressure, extruded through a die, and cut into short lengths. Most of the pellet plants in Central New York and northern Pennsylvania are associated with a sawdust-producing lumber-related retail business such as pallets or furniture.

(Life-cycle analyses of wood chips show extremely favorable greenhouse gas emission reductions for pellets derived from such manufacturing waste when replacing natural gas.[11] The largest of these pellet plants, New England Wood Pellets (NEWP) with facilities in Schuyler and Deposit, NY, primarily uses a mix of mill residues and waste wood from logging operations. The other pellet plants are medium-sized pellet mills that report production around 35,000 tons/year. Currently, there is an enormous global wood pellet market with 3.2 million tons of pellets exported by the US in 2013, primarily for use in European power plants. [45]

Agricultural biomass varies widely and is still in its infancy both in terms of equipment that can effectively and cleanly burn the material and in understanding and controlling the emissions from the various materials. Researchers at Cornell University and Brookhaven National Laboratories, among other institutions, are studying emissions from agricultural biomass, with others working on improving combustion equipment design to better handle the feedstock and burn it more cleanly.

Issues with agricultural biomass (including dedicated energy crops) include higher ash, nitrogen and phosphorus content, as well as naturally occurring chlorine and other salts, depending on the crop and inputs added to increase yields and combat natural competitors and pests. These result in higher emissions related to these components (e.g., NOx). The higher chlorine content can be corrosive to combustion equipment. In addition, naturally occurring silica found in many of the grasses used for energy leads to the formation of “clinkers”—hard deposits similar to volcanic glass—that can harm the combustion equipment. While the feedstock presents inherent challenges not found with wood, advances in combustion technology are already addressing many of these.

Figure 2. Biomass comes in many forms, the most common of which are saw logs from local harvests, which are turned into cordwood, wood chips, or lumber. Wood pellets are made mostly from waste wood from local lumber mills.

2. Potential of Biomass Production in Tompkins County

2.1 Amount of Land Available

The Tompkins County Planning Department’s recent GIS analysis (conducted in 2014) of 2012 Land Use Land Cover Data shows that, for the purposes of biomass supply, Tompkins County can be divided generally into forested land suitable for production of woody biomass; inactive agricultural, brush and grass lands suitable for planting dedicated energy crops; and active agricultural lands suitable for harvest of agricultural waste products. Of the total 305,666 acres of land in Tompkins County (not counting the 9,408 acres in Cayuga Lake), there are roughly 141,056 acres of forested land; 11,938 acres of grassland, 27,431 acres of brushland, and 9,984 acres of

inactive agricultural land; and, from the 2012 Census of Agriculture, there were 43,547 acres of active agricultural land. The remaining areas are not generally viable for biomass production.[43]

A GIS-based analysis was conducted to identify "Suitable" lands for biomass production. All of the forest, brush, grass and inactive agricultural lands identified by the 2012 Land Use Land Cover data had the following features removed to determine suitable acreage: designated Unique Natural Areas, lands with slopes greater than 15%, 100 foot buffers on either side of intermittent and perennial stream centerlines, 100 foot buffers on either side of road centerlines, and parcels smaller than 10 acres in size. The analysis concluded that of the total forested land, roughly 49.5% was available for biomass harvest. Similarly, roughly 55.8% of the brushland, 75.5% of the inactive agricultural land and 57.1% of the grassland was suitable for biomass production. Figure 3 illustrates the areas suitable for biomass harvest, showing 69,775 acres of suitable forest land, and 29,668 acres of general inactive agricultural, brush and grass land.

As for the potential for biomass harvests on active agricultural lands based on agricultural residues, a detailed analysis would have to be made of the types of agricultural products currently being grown on those lands to arrive at the biomass products they could yield (e.g., lands producing hay can produce high-quality feed hay or low-quality hay used for bedding; the latter which can also be pelletized and used for heating). This is beyond the scope of this report, but a rough estimate follows.

As shown in Table 2, active agricultural land in the county totals 43,547 acres. Of those acres, roughly 8,232 acres are in corn for grain. It is important to differentiate corn grown for grain, as harvesting methods results in corn stover being left in the field, opposed to corn grown for silage, which results in harvesting the entire aboveground portion of the plant, leaving no stover or residual that can be taken off-site for other uses. Another 24,474 acres of the active agricultural land are forage-land, including hay and haylage, grass silage, and greenchop.[2] Most of the forage-land produces only low-quality hay, which currently only has a market as bedding for livestock, but it is suitable for pellets that can be used in pellet stoves and boilers (and, on a larger scale, briquettes and bricks that can be used in commercial boilers). Taking 2/3 of the forage-land as available for this type of harvest, based on an assumption that 1/3 of the land could produce adequate amounts of bedding material to meet needs, results in 16,316 acres of forage-land for a total of 24,548 acres of land used to grown corn for grain and forage-land, both appropriate for biomass harvest.

Table 2. Top Crops Grown in Tompkins County

Crop	Acres
Forage-land used for all hay and haylage; grass silage; and greenchop	24,474
Corn for grain	8,232
Corn for silage	6,951
Soybeans	2,561
Vegetables harvested, all	1,329
Total	43,547

Source: 2012 Census of Agriculture, Tompkins County, NY. US Department of Agriculture. National Agricultural Statistics Service. 2013.

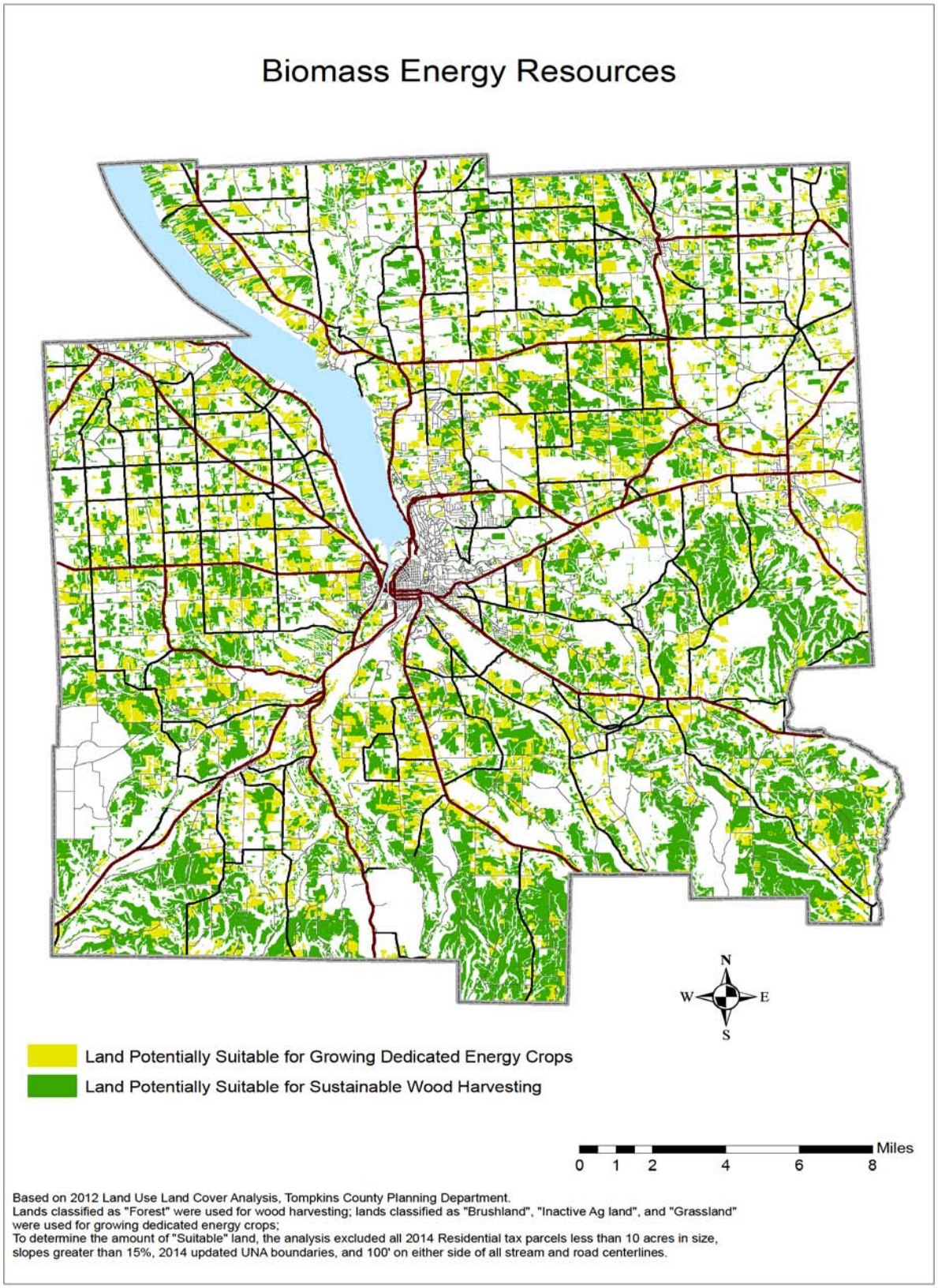

Figure 3. Land in Tompkins County suitable for biomass harvest, TC Planning Dept, 2015

2.2 Energy Potential of Biomass in Tompkins County

Woody Biomass from Forests: Each acre of forests can produce, generally, about a cord of wood on a sustainable basis each year (total aboveground biomass in forests averages about 58 dry tons/acre).[17] Each cord of dry wood weighs roughly 1.5 tons (2.5–3 tons green). Therefore, the 69,775 acres of harvestable forestland in Tompkins County could yield roughly 104,663 tons/year. The 2007 Tompkins County Forest Management Plan provided an analysis of the mix of trees growing on 600 acres of county-owned forestland in the Towns of Newfield and Caroline. The analysis revealed that they contained an average heat value of 6,429 Btus/lb (based on the heat density in dry wood).[39] Therefore, the harvestable biomass from forests in the county could yield a heating value of roughly 1,345,751 MMBtu/year of thermal energy on a renewable basis.

Dedicated Energy Crops from Inactive Agriculture, Brush and Grass Lands: Researchers and farmers across the state (and the world) have been growing dedicated energy crops for decades. The most promising for our region are grasses, such as switchgrass (*Panicum virgatum*), reed canary grass (*Phalaris arundinacea*), and miscanthus (*Miscanthus giganteus*), and short-rotation trees such as shrub willow (*Salix* spp.). These generally require relatively little in the way of herbicides to allow them to establish or fertilizers to produce sufficient yield. One of the more promising, switchgrass, can yield between 3 and 8 dry tons/acre/year, with a heat value of roughly 15.5–16.5 MMBtu/ton.[18,29] Taking middle values of 5 dry tons/acre/year and 16 MMBtu/ton, Tompkins County's 29,668 acres of inactive agricultural, brush and grass lands could thus provide roughly 148,340 tons of biomass/year, which can offer 2,375,440 MMBtu/year. Shrub willow has a similar energy profile, with an average of 4.7 dry tons per acre and roughly 15.5 MMBtu/ton, while being lower in ash.[44,48]

Agricultural Waste from Active Agriculture: Looking at active agricultural lands, according to USDA estimates, New York corn yields have been between 130 and 150 bushels per acre.[25] For approximately every 42 bushels of corn grain produced, one dry ton of stover is produced.[35] Therefore, roughly 3 dry tons of corn stover can be taken from every acre, resulting in roughly 24,696 dry tons of corn stover from the 8,232 acres currently growing corn for grain. Using the value of 16,316 acres of forage-land that can produce low-quality hay, with a yield of roughly 1.7 tons per acre,[25] this results in roughly 27,737.2 tons per year. With a heat value of roughly 15.5 MMBtu/ton for corn stover and roughly 15 MMBtu/ton for hay,[29] in all, at current usage characteristics, biomass from active agricultural lands therefore has the potential to provide roughly 798,846 MMBtu/year.

It must be noted that, particularly regarding corn stover, not all of the material can be removed, as some should stay in the fields to return nutrients to the soil. Leaving an adequate amount of material is included in the production figure of 3 dry tons of stover per acre, above. Some studies have shown that when the stover is the main source of nutrients back into the soil, there is an allowable stover harvest rate of as low as 0.73 tons/acre to as high as 1.9 tons/acre (depending on the root:shoot ratio).[6] Alternatives include using manure or a rotation crop such as alfalfa, both of which are commonly done in our area and both of which allow for greater total stover harvest.

It should also be noted that, according to the Renewable Fuels Roadmap and Sustainable Biomass Feedstock Supply report,[33] changes in land use and improvements in fertilizer technology and land use management are expected to result in greater yields on existing active agricultural lands, with a similar increase in productivity of inactive lands with a potential to grow dedicated energy crops, so that the potential for heating homes with biomass from dedicated crops grown on both active and inactive agricultural lands in the county will be even greater in 2020 and beyond. Finally, changes in moisture and temperature (as well as pests and diseases, CO_2 levels, and other factors) due to climate change are expected to result in altered agricultural patterns in our

area, though it is difficult to know exactly which crops may benefit from these and which ones may be harmed, and to what extent.[9]

In summary, the total thermal energy that can sustainably retrieved from forests and inactive and active agricultural lands in Tompkins County is approximately 4,518,037 MMBtu/year, with 1,345,751MMBtu/year coming from forestlands, 2,375,440 MMBtu/year from inactive agricultural, brush and grass lands, and 798,846 MMBtu/year from active agricultural lands.

Based on the 2008 Tompkins County Greenhouse Emission Inventory, the average heating demand per household is 91 MMBtu/yr for the 37,443 households. It should be noted that the total heating demand in the County, ~5,208,990 MMBtu/yr at the 2008 level, includes the residential, commercial and industrial sectors, not just the residential sectors.

In addition, other oft-overlooked resources, such as waste wood, could be used for heating facilities. According to Jeanne Grace, Ithaca City Forester, the city harvests approximately 100 trees, with an average diameter at breast height (DBH) of about 25".[27] Most of this wood is now mulched and given away for free to city residents (a small amount is burned in a wood stove in a facility in Stewart Park and some is taken home for burning by city employees). At roughly a ton per tree of this size, this represents roughly 100 tons of wood from within the city alone. This is not included in any of the estimates in this report, but could be considered in the future, and expanded to the county-wide level.

2.3 Existing Combustion Equipment Efficiencies and Relative Sizes

While not incorporated into this analysis, efficiencies of the combustion equipment will reduce the potential of biomass to supply heat because while the raw feedstock can provide a given amount of energy, the combustion equipment's efficiency will reduce that total amount accordingly. Current combustion equipment varies in efficiency from as low as 30% or less for an outdoor wood boiler and as low as 50% or less for a pre-1990 wood stove (when EPA emissions regulations went into effect) to 80–85% for many pellet stoves and greater than 90% for pellet boilers and some wood boilers. According to 2011 U.S. Census estimates, there were nearly 2,000 wood stoves in operation in Tompkins County at that time. The number of pre-1990 wood stoves in operation in the U.S. is estimated to be in excess of 70%, so we can assume that more than half of the 2,000 wood stoves in the county function at efficiencies at or below 50%. However, heating with wood is increasing in popularity, so the proportion of more efficient wood stoves is almost certainly higher and should continue to grow in the future. Further, the EPA released revised regulations for all wood-combustion equipment in early 2015, with even stricter emissions levels (while not always perfectly aligned, emissions are generally inversely related to efficiencies, so as emissions drop, efficiencies increase).[36]

We do not have any reliable data for numbers of pellet stoves and boilers currently being used in Tompkins County. However, through informal surveys with local wood and pellet stove retailers, we believe the proportion of biomass-fired heating equipment in the county overall to be roughly 60% wood stoves, 30% pellet stoves, about 5% outdoor wood boilers, and less than 1% for both advanced pellet and wood boilers. Again, the total number and proportion of higher-efficiency equipment is expected to increase substantially over the next 10–20 years.

2.4 Carbon Sequestration

It is important to consider that forests and even dedicated energy crops can also help sequester carbon, since properly managed forests and fields are more productive than non-managed ones. As one study noted:

> "Northeastern forests sequester 12 to 20 percent of annual CO_2 emissions from the region, mostly in living plants and soil. This sequestration capacity figure includes all

> management regimes—practices that enhance carbon sequestration, are carbon neutral, or actually result in net carbon emissions. By expanding excellent forestry [forestry that is ecologically, economically, and socially responsible] in northeastern forests, the percent of annual emissions that can be sequestered by forests can be substantially raised. Excellent forestry can help increase the amount of carbon sequestered in forests while also harvesting wood products and protecting ecological values."[10] (See also *Forest Management*, below.)

In a recent study of eight counties across the Northeast and Mid-Atlantic and the city of Baltimore, researchers concluded that "The rural counties (those with populations under 100 people per km^2)[Tompkins has 76 people per km^2] could offset a significant portion of current CO_2 emissions (up to 42%) by expanding forest CO_2 sinks and, in some cases, by growing bioenergy crops, but protecting existing forests from overharvest and land-use conversion will be critical."[24] They go on to say that "Forests are the largest potential CO_2 sinks in rural counties and sequester 18%–420% of annual CO_2 emissions in the studied counties (77,000–511,000 Mg [84,878–563,281 tons] of carbon per year)." [24] In summary, "Together, afforestation and bioenergy could offset 0.3%–28% of the CO_2 emissions in rural counties." [24]

In previous studies, some of the same researchers looked in more detail specifically at carbon mitigation strategies in Tompkins County alone and found that 133,379.7 tons carbon/year could be sequestered by the county's forests and active and inactive agricultural lands (including soils).[4]

The authors also point out the importance of considering the albedo effect, or the variability among materials (and land cover) to reflect or absorb the sun's energy. Commercial development of forests or agricultural lands, particularly when adding a large amount of blacktop, contributes considerably to localized warming, which, taken cumulatively, can have a significant global effect.

3. Opportunities and Challenges

Biomass represents an opportunity to significantly reduce the county's carbon emissions, but it also has several additional environmental and economic advantages over fossil fuels, as well as some significant challenges.

3.1 Demand from the Various Sectors

The greatest near-term opportunity for biomass utilization locally is to replace oil and propane for space and process heating. Home heating oil and propane are currently the most expensive fuels and there are still many homes and businesses in Tompkins County using both.

According to 2011 U.S. Census estimates, there were nearly 2,000 wood stoves in operation in Tompkins County. Many provide primary heat to homes at least part of the year. For primary heat, each home/wood stove burns an average of 3–5 cords of wood per season, with some burning considerably more. State law limiting the transport of wood to 50 miles means all of this is derived from forests within or neighboring the county. The unpredictable and generally increasing costs of fossil heating fuels have resulted in an increase in the number of homes using wood (cordwood and pellets) to meet at least some of their heating needs. Newer combustion technologies have significantly improved emissions and efficiencies over older wood stoves, so an increase in the use of more efficient wood stoves should result in less of an increase in demand for wood (and emissions) than would be extrapolated from current wood stove use.

It is estimated that up to 70% of wood stoves in operation nationally were built before 1991, predating the Phase II EPA certification process governing most of the wood stoves that fall under

any regulations. Wood stoves conforming to the latest EPA rules released in early 2015 are almost non-existent at this time, but will slowly begin making inroads into the market. NY State recently introduced a program—Renewable Heat NY—that includes significant incentives for changing out older wood stoves for pellet stoves and outdoor wood boilers for advanced two-stage gasification wood boilers or advanced pellet boilers. These are intended to address air quality issues arising from older wood stoves and boilers, but will also effectively reduce the demand for cordwood per unit. In addition, because pellets are primarily derived from mill waste, converting to pellet stoves will further reduce this demand.

With these conditions in mind, it is difficult to forecast future demand on our forests for cordwood, however we were able to estimate the existing demand to be 192,870 MMBtu[1], or approximately 14% of the total potential energy in forest biomass of 1,345,751.

In addition to the growing demand for firewood and wood pellets as a result of rising fossil fuel costs, another force acting on the biomass market is the changing demographic of wood stove owners. Many people who heat with cordwood harvest it from their own woodlots; even for those who purchase cordwood, there is a significant amount of physical labor involved. However, an aging population is less able and willing to meet the physical demands required of heating with cordwood, whether from one's own forests or having it delivered. Median age in the Southern Tier counties (with the exclusion of two college student-populated areas, Cortland and Tompkins Counties) is 41–44 years (versus 38 years across New York State and 37 years in the U.S. as a whole).[1] This group is ripe for conversion to wood pellets, especially if bulk delivery of pellets becomes a reality. It represents a population that, unable or unwilling to continue heating with wood, could convert to oil or propane (if natural gas is not available) or, worse, coal, which, in addition to increasing their net carbon emissions, will result in a significant increase in their heating expenses in the case of oil and propane.

> The need to educate residents about the benefits of utilizing biomass for heating, and of the available technologies, is significant. The vast majority of forestland statewide is privately owned[17] and much of that forestland is found in relatively small family plots. Research has shown that many county residents would like to make more use of their land than they are currently doing, including harvesting biomass. For example, in the fall of 2010, Cornell researchers working with Extension agents and others developed a questionnaire that was sent to 2,400 NY State woodland owners.[26] Results, based on 893 completed questionnaires, revealed that 38% of respondents had no interest in selling woody biofuels (representing 42,940 landowners and 2,390,820 wooded acres statewide), 16% had already sold woody biofuels (representing 18,080 landowners and 2,642,485 wooded acres), and 46% were interested in doing so but had not yet done so (representing 51,980 landowners and 3,321,695 wooded acres). The authors noted that, considering non-response bias, the percent with no interest is likely higher. In addition, it should be noted that a significant proportion of those not interested in selling woody biomass were already using wood from their properties for their own personal use.[26]

Similarly, the changing demographic of woodland owners means an aging population that is increasingly pressured to sell forested land, particularly in the absence of viable markets for the forest products. According to some reports, over the next 25 years, three million acres of forestland in the Northeast may be lost to development.[12]

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[1] 5 cords/hh x 2,000 hh using woodstoves = 10,000 cords of wood/year countywide. 1.5 dry ton heat value of each cord of wood x 10,000 cords = demand for 15,000 tons per year of wood.Average heat value for local trees of 6,429 Btu/lb dry wood x 15,000 tons x 2,000 lb/ton x 1 MMBtus/1,000,000 Btu = 192,870 MMBtu of current wood energy demand per year in Tompkins County

Currently, prices paid for woody biomass are very low, and are unlikely on their own to provide much revenue for landowners. However, improved management of a forest parcel for long-term production of high-value sawlogs, with biomass produced as a residue from precommercial thinnings, removal of undesirable species, and tops and limbs from sawlog harvest, could create a favorable scenario for everyone involved.

The other consideration when looking at forces acting on the amount of wood available for biomass from our forests is that we are already seeing the effects of invasive pests, including hemlock woolly adelgid, and emerald ash borer. In the future, these types of stresses are expected to become more commonplace.[3] Historically, here and in other areas of the country, this has led to periods of significantly higher rates of harvesting.

3.2 Combustion Technologies

There have been tremendous advances in wood-burning equipment over the past 20 years. Outdoor wood boilers (a.k.a., hydronic heaters), which are notoriously highly polluting, inefficient, and generally a nuisance and significant source of harmful particulate matter in many communities across the state, are being replaced with modern two-stage gasification wood boilers that can provide heat much more efficiently with emissions that can be on-par with oil-fired systems.[13] Some experts in the field see a tremendous growth potential from these units, stating that, “Heating with wood using modern, small-scale high efficiency/low emission boilers is the next significant economic opportunity in New York in terms of wood energy.”[38] These units allow homeowners to heat their homes efficiently and with low emissions with a boiler or furnace that uses a fuel they may be able to access from their own woodlots.

While pellets and woodchips are not something most homeowners can make themselves, they do offer two main advantages over cordwood: they can be sourced from mill waste and small-diameter forest residues left over from logging operations, and, as a fuel, they can flow in mechanized systems for automatic feed to the combustion equipment, resulting in very little physical labor at the combustion source. Pellets offer the additional advantage of being a relatively uniform, dry, and dense fuel, resulting in typically higher combustion efficiencies and lower emissions than cordwood in wood stoves and boilers. Compared to wood stoves, pellet stoves also take the operator out of the equation—whereas even the newest, most advanced wood stove can be abused by the owner, who may burn wet wood or other even more harmful materials that can result in high levels of dangerous emissions, pellet stoves simply do not operate on anything but dry pellets. Pellet stoves and boilers have oxygen sensors that control the burn, they often come with or can be connected to a thermostat, and require only a small amount of electricity to run (with some models now coming with battery backup and kits available for the ability to provide battery-backup power to any pellet stove). Pellet boilers can also be fed automatically, with either augured or pneumatic feed systems. Such systems are available at scales from as small as roughly 50,000 Btu/hr up to more than 1.5 MMBtu/hr for single pellet boilers (and the boilers can be connected in series to meet virtually unlimited demands).

Currently, CCETC is working on a Cleaner Greener Communities program to bring bulk wood pellet delivery to the Southern Tier Region. This will allow residential and commercial end-users to convert to fully automated, advanced pellet boilers, which in effect mimic their current experience with oil or propane in that they are automatically fed from storage containers that are typically housed outside and are filled on a delivery schedule just as propane or oil is. Operators will have to empty their boiler’s ash pan roughly once to twice a month, but otherwise, from the home- or business owner’s perspective, the systems operate much like their oil or propane boiler—yet they will be realizing significant financial and carbon savings compared to oil or propane.

Figure 4. Pellets can be delivered in bulk to home- and business owners with residential and commercial boilers, creating the ease of use of oil and propane at about a third of the cost.

Chip systems are most effective in the commercial and industrial sectors, at heating loads of greater than 2 MMBtu/hr (although there are chip systems as small as 100 KBtu/hr). Chips are typically cheaper than pellets since they require less processing, but their up-front expense can be considerably higher than other systems owing to the need for more robust augers, moving tables, loaders, and other management systems to effectively feed the fuel to the boiler (but because of low fuel costs, chip systems can be cost-competitive over time). Wood chip boilers can be scaled up to provide several million Btus/hour very cost-effectively and, depending on scale, with added scrubbers and/or precipitators, with very low emissions.

There are local and regional examples of each of these, with a growing number of residential wood stoves and advanced two-stage combustion wood boilers, as well as pellet stoves and advanced pellet boilers. At the larger scale, local examples include, among others, the following:

- a 0.5 MMBtu wood chip boiler heating Cayuga Nature Center since 2009;
- another similar but smaller boiler at the Danby Highway Department's main barn (which due to significant design issues has had operational problems that are currently being resolved);
- a 1.7 MMBtu wood pellet boiler recently installed at a 50K sq. ft. greenhouse in Triangle, NY, as part of the Cleaner Greener Communities-funded Bulk Wood Pellet Infrastructure Boost Program, that has saved them more than $40K in heating bills in its first season;
- a combined heat and power (CHP) chip boiler (actually two 350 hp boilers) at the 1-million-square-foot VA Medical Center in Canandaigua that has been operational since 2013 and can provide 345 kW of power and 604 KBtu; and
- a similar CHP system on which it was based located at the Lockheed Martin facility in Owego consisting of two 600 hp wood chip boilers that provide space heat to the 1.8-million-square-foot facility as well as steam to absorption chillers to provide cooling in the summer (on-line since 2008).

Combined heat and power (also called "cogeneration") systems such as these may have the greatest potential to make efficient use of our biomass resources, particularly at large scales. While not uncommon in Europe, these systems are only now starting to become economically viable in the United States, but, because of rising fossil fuel costs, are expected to be more so in the future, and could certainly come to maturity within the timeframe of this roadmap. These systems distribute the heat produced by electricity production for more efficient energy capture. Conversely, heating systems can be fitted with small generators to produce electricity that can be used on-site or put back into the grid. CHP systems currently exist at scales ranging from residential to industrial and utility scale (systems <5 MW and considerably smaller are sometimes referred to as "modular CHP systems" because they are typically put together from pre-engineered components that can be assembled on-site). Currently, particularly with respect to the smaller systems, biomass-fired CHP is not economical. But CHP systems running on natural gas are growing in popularity, and as

fossil fuel costs continue to increase and equipment costs drop, biomass-fired CHP is expected to become economically competitive.[37]

Another important consideration is that costs of purchasing biomass-fired CHP systems tend to be higher than those for fossil fuel-fired systems. Fuel costs can give biomass systems a significant financial advantage over time, but up-front costs can be a barrier to their wider adoption. Efforts are being made to have biomass-fired heating equipment included in incentive programs with other renewable energy systems; something that would help significantly both in bringing their costs down and bringing them to broader attention. And, of course, as they become more common, costs will come down, due to increased competition, a shared knowledge of how to design and manufacture the units, and economies of scale.

Biomass CHP systems, particularly at the larger scale, also tend to require more maintenance than fossil fuel-fired systems. Therefore, institutions that have on-site personnel who can clean out and adjust the systems as needed are best suited for their implementation—although in many cases installers offer maintenance plans.

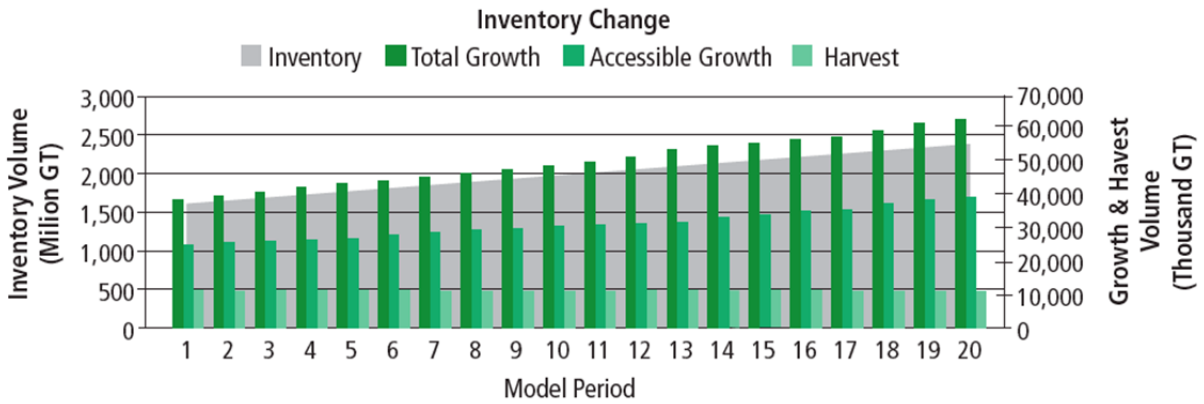
3.3 Forest Management

Currently, our forests are not managed to any great degree. For many years, growth in NYS forests has been significantly greater than harvests, with estimates ranging from 2.1:1 to 2.5:1 for the past several years.[17] This has resulted in a high proportion of low-quality and densely stocked stems due to past land use. Approximately 20% of NEWP's feedstock is derived from debarked and bark-on bole chips, processed from low-grade and generally small-diameter trees that are harvested during forest management operations on both public and private forestlands.[25] These trees are misshapen, diseased or of small diameter, and do not have higher-value markets. As NEWP utilizes only the bole portion of the tree, the nutrient-dense tops and branches of these trees are severed in the woods to recycle nutrients into the soil. The removal of these trees during harvesting is vital to creating healthier forests, since they otherwise would be left behind to become the future forest of poor-quality trees. With good low-grade markets, foresters and loggers can conduct proper thinning operations that leave behind good stocking of higher-quality stems that will become future high-value "crop" trees.

According to the Cleaner Greener Southern Tier Regional Sustainability Plan, land use changes in the Southern Tier from 2005–2010 "resulted in a net sequestration of 6,922,505 $MTCO_2e$. Given the high rate of sequestration and the region's plentiful forest resources, improved forest management and targeted reforestation can help increase carbon stocks in the Southern Tier."[8] Indeed, there is significant potential for carbon offsets by improving carbon sequestration in our forests—according to some estimates, as much as two to seven times the carbon offset benefits of emissions reductions planned in some climate action plans (e.g., Canada's) could be generated by forest management practices.[7]

Further, the vast majority of the forests in New York State, and within Tompkins County, are in a phase with a preponderance of mature trees following previous land clearing.[17] In terms of carbon sequestration, this is a period of slower growth (and therefore carbon uptake, with effectively zero carbon capture in a fully mature forest). This provides an opportunity, with good forest management, to increase carbon sequestration and harvest/thinning for long-term management.[10,28] Therefore, while total forest growth has exceeded harvest by a factor of between 2.1 and 2.5:1, [17,38] resulting in an increase in standing volume of timber of approximately 8% from 2005 to 2012,[15] better forest management could increase forest growth (and, thus, carbon sequestration) even further, even with increased harvests. Figure 1 shows the expected change in total biomass in NY State forests over the next 20 years at the present rate of growth and harvest.

Climate change is also expected to add stresses to forests, most notably with changes in temperature and rain patterns, which themselves can add other stresses such as competing invasive plants and harmful invasive pests. Better forest management, including increased harvesting, can "increase forests' resistance, resilience, and adaptation to climate change." [10]



†Inventory totals are for all live, above-ground biomass on timberland.
Source: The Economic Importance of New York's Forest-Based Economy. North East State Foresters Assn. 2013.

Figure 5. Change in Total Biomass in NY State Forests, 2013–2033†

3.4 Environmental Opportunities and Challenges

In addition to the improved forest aspects and carbon emissions reductions possible through converting to biomass for thermal energy needs, if used properly, such a conversion can lead to improved overall air quality. Burning heating oil emits "ambient concentrations of fine particles, … [which] have adverse health and environmental impacts."[21] Although there is a move toward low-sulfur oil, high levels of sulfur in heating oil are "a significant source of sulfur dioxide emissions in the region—second only to power plants. Regionally, the burning of high sulfur heating oil generates approximately 100,000 tons of SO_2 annually—an amount equivalent to the emissions from two average-sized coal-burning power plants." Heating oil is also a considerable source of particulate matter (PM), oxides of nitrogen (NO_x), carbon monoxide (CO), and mercury. The multi-agency group that produced that report, which looked at converting to biomass for thermal applications in the Northeast, concludes that, "A significant transition to biomass combustion in thermal applications can reduce acid rain-causing sulfur dioxide emissions as well as mercury emissions."[21]

Of course, biomass can itself be a significant source of harmful emissions, particularly when fuels such as green wood are burned in old, inefficient combustion equipment. According to the NYS Department of Health, wood smoke is the largest source of carbonaceous $PM_{2.5}$ in rural New York.[14] But an important caveat is that their study focused on outdoor wood boilers, by many orders of magnitude the most polluting home heating option. Modern pellet stoves and boilers, in particular, have greatly reduced emissions, on par with some fossil fuel systems—and education of wood burners so that they learn of the dangers of creating high levels of particulate matter and are made aware of advanced combustion equipment is an ongoing initiative through Cornell Cooperative Extension and others. Across all Northeastern states, there has been an increase in the number of homes using wood as their primary heating source, with New York showing an increase of about 70% between 2005 and 2012.[22] The effects of large increases in the number of irresponsible wood burners should not be underestimated, but because of improvements in the equipment over the past 25 years and tighter emissions standards like those enacted in April 2015, the vast majority of additional biomass combustion will be with advanced, lower-emitting

equipment, increasingly pellet stoves and boilers at the residential scale and even cleaner-burning pellet and chip boilers at larger scales.

One area currently receiving considerable attention is the natural off-gassing from pellets, particularly of carbon monoxide. When stored in an enclosed space within an inhabited building (e.g., house, school), this could become a problem. For this reason, NYSERDA is currently requiring outdoor storage (enclosed storage of pellets but in an outdoor silo, shed, or similar structure) for all systems installed under the Renewable Heat NY and Bulk Wood Pellet Infrastructure Boost Programs.

Biomass is also a much less energy-dense fuel than fossil fuels, even when densified into pellets. By volume, biomass can require 6 times as much space as fossil fuels, or more, for the same amount of energy. At least currently, it can also not be transported through pipelines, so truck traffic would be expected to increase. This will add wear on the roads and increase truck-related hazards as well as carbon inputs unless the trucks are run on a carbon-free source.

Further, the inherent environmental damage caused by fossil fuel extraction and the well-documented, commonly occurring leaks during processing and transportation of fuels like methane, although not currently borne to any great extent by the county, contribute to their negative impacts at the local level and globally through their high carbon footprint. Additionally, spills and accidents of fossil fuels should be part of the analysis, with the scale of any biomass "spills" being negligible by comparison.

3.5 Economic Opportunities and Challenges

Increased utilization of biomass from area forests will have several economic advantages, including increased revenue and jobs in the harvesting, processing, and transportation of the fuel; new markets for low-grade timber; installation and maintenance of combustion equipment; potentially, local manufacturing of combustion equipment; and monies saved by consumers currently heating with more expensive fuels such as oil or propane.

According to the Northeast Forest State Foresters Association's latest report, "The annual value of sales or output of New York's forest products industry totals over $ 9.9 billion while the forest-based recreation economy is worth $8.2 billion. Approximately 43,912 workers are employed in the forest products, maple and Christmas tree sectors while another 31,926 jobs are found in the sectors that include and support the forest recreation economy."[38] More specifically to woodland owners, the report states that, "The sale of timber products in New York provide[s] forest owners with around $250 million of revenue annually. Many owners rely on these funds to pay real property taxes related to their ownership." [38] With a very limited forest products industry locally, this attribute has not been realized to any great degree; improved local markets for forest products would give forest owners incentive to keep those lands in productive forest.

Several studies have shown that utilizing biomass and other renewables creates more jobs than fossil fuels. For example, a 2009 study concluded that, "All non-fossil fuel technologies (renewable energy, EE, low carbon) create more jobs per unit energy than coal and natural gas."[30] The authors add that, "An increasing number of studies are finding that greater use of renewable energy (RE) systems and energy efficiency provides economic benefits through job creation, while at the same time protecting the economy from political and economic risks associated with over-reliance on a limited suite of energy technologies and fuels." [30] (While their analysis focused on utilizing biomass to produce electricity, they found that biomass resulted in 0.21 total average job-yrs/GWh, which is not only more than fossil fuels, but also more than wind, nuclear, and carbon capture and storage.)

Summary & Recommendations

Biomass is an important part of the renewable-energy sector, with significant potential to provide affordable heating, reduce greenhouse gas emissions, create local jobs, contribute to the local economy, and improve forest health and biodiversity. Advances in combustion equipment will result in lower emissions, the main concern with increased use of biomass for heating. Additionally, advances in combined heat and power systems will make them more viable for both small- and large-scale applications.

While by far the oldest renewable energy technology in use (unless you count simple solar heating), new high-efficiency, low-emissions equipment, coupled with rising fossil fuel costs for heating, are expected to make biomass for heating attractive to a new generation of both home- and business owners.

The county should encourage the wider, responsible use of biomass for home and business heating. There remain concerns about the appropriateness of using biomass for heating, particularly in urban settings. Improved combustion equipment already available is making the technology more widely practical. Judging by significant advances in equipment design over the past decade that reduce emissions and improve fuel handling (in the case of pellets and wood chips), the biomass-fired heating equipment of the future (within the timeframe of this roadmap) could allow widespread use of our local biomass resources for home and business heating without significant negative impacts. That said, biomass should certainly not be considered the only answer in every situation, but rather an important and significant part of our future clean energy mix.

But, as a bulletin from the Forest Products Laboratory concluded:

> "The technology to generate energy from wood has entered a new millennium, with virtually limitless possibilities. As public and private sector support increases, the availability of small modular biomass systems ranging from 3 kWe for homes to 5 MWe for large sawmills will flourish. Future systems will be capable of utilizing a variety of waste residue."[49]

We are already seeing some of these systems. Stakeholders, including Cornell Cooperative Extension of Tompkins County, should continue to educate homeowners about the responsible use of biomass for heating in order to limit harmful emissions. Various sectors of the community also need to be informed about the available technologies so that older equipment is replaced with advanced, cleaner-burning appliances, and new adopters are aware of the benefits of buying the latest equipment. These efforts are underway and continuing and should lead to wider adoption of biomass, particularly for heating.

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Definition of terms: (mostly taken from the Renewable Fuels Roadmap, 2010)[33]

Agricultural Residue: Agricultural crop residues are the plant parts, primarily stalks and leaves, not removed from the fields with the primary food or fiber product. Examples include corn stover (stalks, leaves, husks, and cobs); wheat straw; and rice straw.

Bioenergy: The production, conversion, and use of biomass to manufacture fuels and substitutes for petrochemical and other energy-intensive products.

Biofuels: Biomass converted to liquid fuels such as ethanol and biodiesel.

Biogas: A gaseous mixture of carbon dioxide and methane produced by the anaerobic digestion of organic matter.

Biomass: Any plant-derived organic matter. Biomass available for energy on a sustainable basis includes herbaceous and woody energy crops, agricultural food and feed crops, agricultural crop residues, wood residues.

Bioheat: Thermal energy (heat) provided by burning of biomass.

Bioproduct: Ancillary products made through processing biomass, usually through chemical or thermal conversion to its basic sugars (include products such as cosmetics, plastics, etc. commonly made with petrochemicals).

British Thermal Unit (Btu): The amount of heat energy needed to raise the temperature of one pound of water by one degree Fahrenheit.

Corn Stover: The refuse of a corn crop after the grain is harvested, including stalks and cobs.

Dry Ton/Oven-Dry Ton: Two-thousand pounds of biomass on a moisture-free basis, meaning material without any water content that can be removed by oven drying.

Feedstock: Raw materials that may be treated or converted to create fuels. Biomass feedstocks in New York include forestry products, crop residues, municipal waste streams, manure and food processing waste.

Forest/Forest Land: Areas dominated by trees generally greater than 15 feet tall, and greater than 20% of total vegetation cover.

Forestry Residues: Includes tops, limbs, and other woody material not removed in forest harvesting operations in commercial hardwood and softwood stands, as well as woody material resulting from forest management operations such as pre-commercial thinnings and removal of dead and dying trees.

Gasification: Any chemical or heat process used to convert a feedstock to a gaseous fuel.

Green Tons: A term used in the forest products industry for a U.S. ton or metric ton (tonne) of freshly cut timber, bark mulch; i.e., undried biomass material. A dry ton weighs less than a green ton (conversion used in the Roadmap: dry tons are calculated as 60% of green tons).

Herbaceous Energy Crops: Perennial non-woody crops that are harvested annually, though they may productivity. Examples include: Switchgrass (*Panicum virgatum*), Reed Miscanthus (*Miscanthus x giganteus*), and Giant reed (*Arundo donax*).

Particulate Matter: Fine liquid or solid particles such as dust, smoke, mist, fumes, or smog, found in air or emissions. It is usually separated into PM10 and PM2.5, which are particles of diameter equal to or less than 10 and 2.5 micrometers (μm), respectively.

Short Rotation Woody Crops: Trees such as poplar and willow that can be used as feedstocks for biofuel. Benefits over traditional row crops include improved soil quality and stability, cover for wildlife, and lower inputs of energy, water, and agrochemicals.

Volatile Organic Compounds (VOCs): Organic compounds that evaporate readily and contribute to air pollution directly or through chemical or photochemical reactions to produce secondary air pollutants, principally ozone and peroxyacetyl nitrate. VOCs embrace both hydrocarbons and compounds of carbon and hydrogen containing other elements such as oxygen, nitrogen, or chlorine.