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Sustainable Woody Biomass as a Renewable Energy Source for the Commonwealth of Massachusetts

An Interactive Qualifying Project Report
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Degree of Bachelor of Science

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Abstract

The production of biomass is one way to harvest abundant solar energy. This report investigates the use of woody biomass in various forms as a source of renewable energy. An investigation was conducted to determine the total renewable quantity of woody-biomass available in Massachusetts as a fuel source. Additionally the report looks at various ways to harness the energy and gives recommendations as to the feasibility, including costs, long-term sustainability and public perception.

Authorship

Cara Macy, Scott Guzman, Richard Doane and Celeste Fay shared the writing responsibilities of the report however each team member focused on writing specific sections. Cara was responsible for writing Section 1 and Section 4, the Introduction as well as formatting and peer editing and the bibliography. Scott was responsible for 3.2.1 and 3.2.2 which included Legislation and Incentives for liquid fuels as well as the investigation into ethanol. Additionally Scott worked on section 4 which compared the results of each technology and worked on formatting. Richard was responsible for the investigation into methanol and the concluding section 5. Celeste was responsible for section 2, the assessment of available biomass in Massachusetts as well as all of section 3.1, an investigation into the potential of burning wood.

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Thank you Professor Thompson for devoting your time and insight into the many problems revolving around our energy crisis. Additionally, your encouragement to learn and use knowledge to help others has inspired us to continue our efforts to improve our society at large.

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1.0 Introduction

1.1Goals

The goal of this project was to assess the feasibility of renewable woody biomass in Massachusetts. An investigation was conducted to determine the total renewable quantity of woody biomass available in Massachusetts as a fuel source. Additionally the report looks at various ways to harness the energy and gives recommendations as to the feasibility, including costs, long-term sustainability and public perception.

1.2 Energy Consumption in the United States

In modern society, our everyday lives depend on energy, from using vehicles to get to work, turning on the lights as we read a book, or taking a hot shower in the morning. “Access to energy is fundamental to our civilization, and economic and social development is fueling a growing demand for reliable, affordable and clean energy. Moreover nearly 1.6 billion people, or roughly a quarter of the world’s population today, lack access to modern energy services” (Riemer, 2004). As technology increases, so does the world’s population and our consumption of energy. Along with this increase in need, comes a development of science and an understanding of the impact our fuel consumption has on the environment and the world. No longer is the environment an isolated factor to our energy consumption, but rather an integral and fundamental factor, that must be considered, and is growing in importance as we develop into the 21^{st} century.

Currently, oil, coal, and gas represent approximately 90 percent of commercial energy used across the globe. (Riemer, 2004) If we concern ourselves with the effects this consumption has on the United States, we must first look at the population and how it has changed over the years. According to the U.S. Census Bureau, in 1915 the population of the United States reached just over a hundred million people (100,546,000). (U.S.Census Bureau, 2000) That number doubled in a little over fifty years. In 1968 the census had the population at 200,706,052 (U.S.Census Bureau, 2000). Again, on Tuesday, October 17, 2006 the U.S. Census Bureau estimated that the United States population officially reached 300 million (Tolbert, 2006), adding an additional one hundred million to our countries population in a rather short amount of time. The general consensus for our population is that it is only increasing and by the year 2043, we will have added yet another one hundred million people to the population, with each one hundred million being added more quickly than the last. How does this affect the energy problem? While our population has increased, according to the World Energy Council 2004 Survey, our reserves have not. “The amount of proved recoverable coal reserves in Canada, Mexico and Greenland has remained static, with a slight decrease reported for the USA. Total reserves for North America amount to about 250 billion tons.” (Riemer, 2004)

As our country runs out of viable resources, we must search for other means to get the necessary energy to sustain today’s society. One option for energy resources is foreign oil. As seen from the figure below, the United States doesn’t have an exceedingly large oil reserve, while the Middle East contains well over 50 percent of the world’s reserves. However, internal conflicts within that region and hostile governments have caused us to go to war, and have caused much bloodshed. Many researchers, such as Nayna Jhaveri, a professor at the University of Washington, claim that going to war with Iraq was primarily, if not entirely, due to the oil reserves there. In fact, in 2001 a poll was done that determined that 83% of Jordanian people were convinced that the United States was going to war for oil (Jhaveri, 2004). Some critics have even gone as far as to call our country petroimperialists (Jhaveri, 2004). When does the cost of human lives outweigh the cost of energy? A website dedicated to the daily upkeep of tracking civilian lives cost due to the war puts the most recent death count at 82,856 – 90,390 (Iraq Body Count, 2008). And these are just documented civilian deaths from violence, while the estimates for the actual deaths caused are much higher, but no concise numbers are reported. Clearly alternatives need to be found.

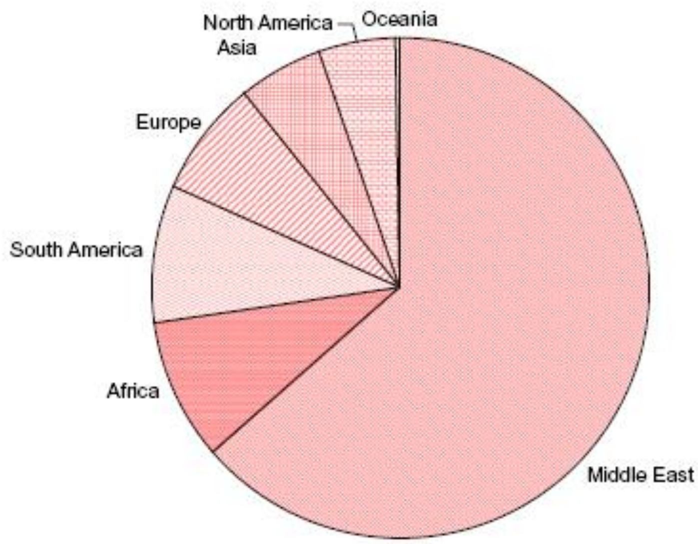

Figure 1 – Proven oil reserves at end-2002: regional distribution
(Riemer, 2004)

Along with the dependency on foreign oil there is the environmental impact. Climate change and global warming are terms that are no longer considered debatable science by the majority of society, but rather a gloomy foreshadowing of our world's fate as we continue on our current trend of fossil fuel burning and carbon emissions. Fuel resources are no longer looked at for just their overall quantities, efficiencies, and cost of production; but now social and environmental impacts are of increasing concern.

There is a particular anecdote that relates to petroleum and the world's old school of thought. The following story reflects how we looked at fuel in the past and reflects how we need to change our style of thinking if we want to live in a sustainable world.

> "In the 1920s the American entrepreneur, Henry Doherty, became troubled by the 'crude and ridiculous' way that oil producers were operating. Since the mid-19th century the industry had been governed by the 'rule of capture', a principle based on an old English law for hunting migratory animals. This meant that every time a new oil field was struck, there was a scramble among producers to drill into the structure the fastest and to draw off as much oil as possible before their competitors. Mr. Doherty recognized that such a haphazard way of drilling was leading to volatile prices as well as damaging the underground pressure needed to bring oil to the surface. To the amazement of the industry he suggested that oil fields should be 'unitized' or drilled as single entities. The number of wells could be limited to

preserve the underground pressure for longer and output would be apportioned to the various partners on the basis of their shareholding in the field. This idea—the first time cooperation had been suggested in the ultra-competitive oil industry—was at the time radical and unpopular. It took Mr. Doherty several years of hard lobbying until unitization became an accepted practice. Today, the oil industry remains as competitive as ever but more readily recognizes the value of partnerships in some parts of the business." (Riemer, 2004)

The previous story reflects a cutthroat business style of the past that was not successful, and is an example of why it will continue to not work in solving our current energy problems. Instead, we need to band together to solve our global energy dilemma. This means that there will not be one solution, but rather a collaboration of alternative energy sources that will aid us as we develop into the 21st century. While there may not be any single fuel source capable of replacing fossil fuels, a combination of all different "green" resources could make a significant change in not only our dependence on oil but all of the benefits associated with energy independence. A decrease in the amount of fossil fuels burned around the world will reduce greenhouse gas emissions and thereby result in a chain reaction leading to an improved environmental footprint and localization of energy resources which would lead to the decline of tensions between countries over oil. We must look to biomass, wind, solar, hydro, and nuclear as potential fuel sources for a sustainable future.

1.3 History of Wood as a Resource in Massachusetts

Harvesting trees in the state of Massachusetts has a bitter past, and therefore the focus of this report is on how to sustain tree growth and harvest wood in a feasible manner. Before getting into the processes, we must first understand the recent ecological history of the forests of Massachusetts. Although European settlers were coming into our state around 250 to 350 years ago, it was not until the peak of agriculture that the greatest decline in tree coverage occurred approximately 150 years ago (O'Keefe, 1998). "Increasing rates of deforestation through the late eighteenth century led to a peak in 1820-80 when more than 80% of the land was open. Reforestation on abandoned fields commenced in 1850 and increased progressively through the early twentieth century." (Foster, 1992) See Figure 2 and Figure 3 on the next page for more details.

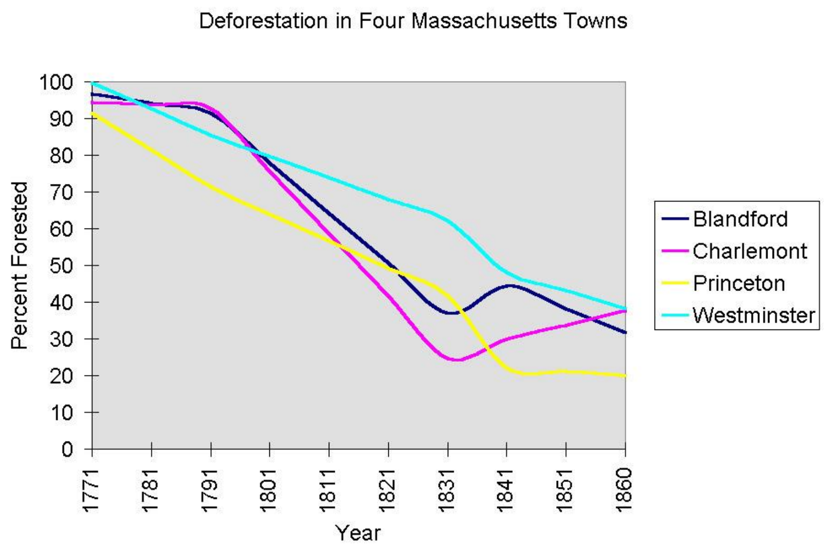

Figure 2 – Deforestation in Four Massachusetts towns, Part 1
(Gerwein, 2007)

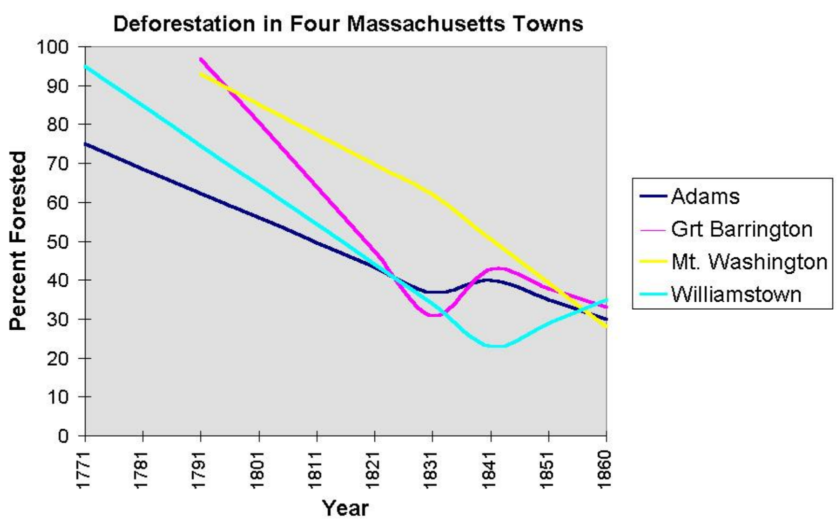

Figure 3 – Deforestation in Four Massachusetts towns, part 2[1]
(Gerwein, 2007)

The main source of deforestation in the late 19th century, early 20th century, was due to a number of reasons, from growing populations, immigration, need for agriculture,

[1] For Figures 2 and 3 "the graphs are based on Massachusetts valuation records, which list acreage in tillage, pasture, forest, etc. Data for the four towns in the first graph were available for the years 1771, 1791, 1831, 1841 and 1860. Data for the four towns in the second graph were available for the years 1771

and the booming logging industry, logging that was done for a number of reasons, from clipper ships to new homes, to the major glass industry at the time. One of the main sources of this was the boxboard industry and their need for white pine. This was at a time where cardboard had yet to be invented. The industrial boom ended for Massachusetts in the 1920s and since then logging has not been a major industry for the state.

The outcome from our forestry history is that there is a rather small percentage of old forest growth left. Old growth forests cover as little as 0.5 percent of our forests in Massachusetts. (Gerwein, 2007) Also, during that time there was a great emotional impact on the people of that era, as the bald landscape is embedded in many memories.

In turn, it has been noted that Massachusetts has some of the strictest forestry regulations in the United States, to the point that many of our forests are under harvested (O'Keefe, 1998). With any ecological setting there is a balance, and our report's goal was to find the balance of sustainable harvesting of this renewable resource to better aid our futures need for alternative fuel sources.

1.4 Public Perception

Forests provide ecosystem services including climate regulation, freshwater supply, stormwater mitigation, nutrient regulation, biodiversity, soil retention and aesthetics valued at $2.9 billion (Natural Resource Based Economic Development, 2007). This means that for the residents of the Commonwealth, it is important to assess possible impacts on these economic resources. Outside of the economic concerns are the negative environmental impacts such an overtaking may have in our state. The main list of species that could be effect by mass harvesting of trees would be the Golden-Winged Warbler, Vesper Sparrow, and the Indiana Myotis (National Wildlife, 2007). These are all species that live in forest habitats and are on the threatened or endangered wildlife list. However, the majority of the animals that are threatened or endangered in the state of Massachusetts live in estuaries, marshes or beaches, where there are no trees to harvest. Therefore, the concerns for the endangered wildlife would be minimal.

2.0 Massachusetts Woody Resources

2.1 Sources of wood

2.1.1 Net Annual growth

Of Massachusetts' 5 million acres, 3.1 million acres are forest land which totals approximately 62 percent of the state's total area. Figure 4 shows the distribution of harvesting and land-conversion activities throughout Massachusetts.

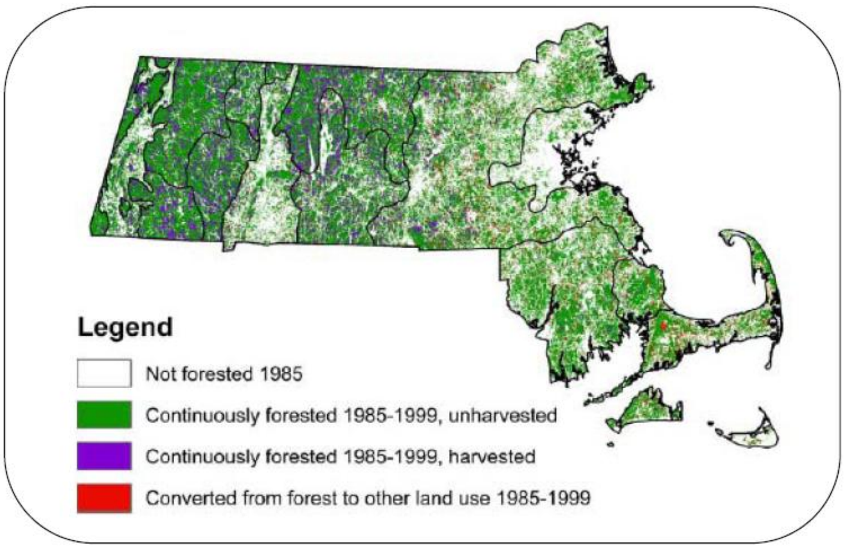

Figure 4 – Distribution of harvesting and land conversion activities.
(Renewable Biomass From the Forests of Massachusetts, Forest Harvesting Systems for Biomass Production, 2007)

Forest land is categorized into urban forest, other forest, and timberland. Urban forest land, which makes up 5 percent of the state, is land sufficiently productive to qualify as timberland, however it is completely surrounded by or nearly surrounded by urban development. Other forest land, which also makes up 5 percent of the state, is incapable of producing 20 cubic feet per acre per year of industrial wood under natural conditions, because of adverse site conditions. Timberland makes up 52 percent of the state, and is defined as forest land producing or capable of producing crops of industrial wood and not commercial forest land. This means that timberland is capable of producing 20 cubic feet per acre per year of industrial wood. Because of the difficulties surrounding urban and other forest land and their small area, timberland will be focused on.

Timberland can be classified in several different ways; however the national standard is to use relative stand density. The types of trees and some of their properties including general locations throughout the state, general uses, average density and other notes are shown in Table 1. Table 2 shows the percentage and equivalent acres of Massachusetts timberland by forest type. (Alerich, 2000)

Table 1 – Tree Species and their properties in Massachusetts forests (Common Native Trees)

Type of Tree	General Location	General Uses	Density	Notes
Eastern White Pine (most abundant species) Pinus strobus	Throughout the State	Lumber, millwork, moldings	LIGHT 417 kg/m^3 (air dry) 400 kg/m^3 (12%)	
Red Maple(2nd most abundant) Acer rubrum	Woodlands throughout the state	Nice colors in leaf season	MEDIUM 490 – 540 kg/m^3	b/c of low value, growing much faster than cut
Eastern Hemlock Tsuga canadensis	Throughout the state woods	Rough construction	LIGHT 410 kg/m^3	Important for wildlife but has a tree disease caused by the "wooly adelgid"
Northern Red Oak Quercus rubra	Throughout the state woods	Very coveted used in furniture & flooring	HEAVY 640 kg/m^3	Cutting faster than grown (some concern)
Sugar Maple Acer saccharum	Throughout the state woods	Foliage trees Maple syrup trees Furniture & flooring	HEAVY 630 – 680 kg/m^3	Negative effects from global warming and acid rain
Black Cherry Prunus serotina	Thrives near Connecticut river valley	Furniture & cabinets	MEDIUM 540 kg/m^3	Will benefit from global warming
White Oak Quercus alba		Furniture & flooring. Large acorn important for wildlife	HEAVY 680 kg/m^3 769 kg/m^3 (12%)	
Red Spruce Picea rubens Sarg.	Higher elevations Berkshires	Building construction	LIGHT 400 – 410 kg/m^3	Will probably die off from global warming
Paper Birch Betula papyrifera	Likes old burn sites and higher elev.	Easily machined	MEDIUM 550 kg/m^3	Will probably die off from global warming
Pitch Pine Pinus rigida	Sandy soil like Plymouth & Cape Cod		MEDIUM 520 kg/m^3	

Table 2 – Distribution of Timberland by forest type.
(Alerich, 2000)

Type	Percentage	Acres

Northern Hardwoods (Sugar Maple, Beech, Yellow Birch, Black Cherry)	39%	1 million
Oak/Hickory	28%	0.7 million
White/Red pine	17%	0.4 million
Oaak/Pine	8%	0.2 million
Elm/Ash/Red Maple	5%	0.1 million
Other	3%	>100,000

Between 1985 and 1999, the average annual net growth on growing stock was 97.5 million cubic feet or 37 cubic feet per acre per year (~0.3 cord/acre/year). During the same time period, the average annual removal of growing stock was 53.9 million cubic feet or 20 cubic feet per acre per year (~0.15 cord/acre/year). This creates a net increase in timberland growth of 43.5 million cubic feet and equates to a 1.7 percent annual growth factor. The 43.5 million cubic feet of net growth is only in reference to the growing stock trees and excludes any branches less than 4 inches. The amount of timberland material less than 4 inches is 18,096,000 dry tons or 26,239,000 green tons (1.45 green tons per dry ton). (Alerich, 2000) If the annual growth rate of 1.7 percent is applied to the branches then there are 446,000 tones of growth to add to the growth of the stock. When the million cubic feet of net growth of stock are converted to tons, (assuming 47 pounds per cubic feet of dry wood) the weight is 1,484,000 tons of net growth. That value added to the branches yields a total unutilized annual net growth of 1,930,000 tons of woody biomass available, as seen in table 3. (Fallon, 2002)

Table 3 – Estimate of Woody Biomass from Unutilized Annual Net Growth in Massachusetts Forests (Fallon, 2002)

Growing-Stock Trees	Net Growth (MCF)	Removals (MCF)	Remaining (MCF)	Remaining (Tons)
	97.5	53.9	43.5	1,484,000
Branches, Top Wood				446,000
Total				**1,930,000**

2.2.1 C&D Waste

Construction and Demolition (C&D) waste is composed of material generated from construction, renovation, repair and demolition for roads, bridges and buildings. The material can include wood, steel, concrete, masonry, plaster, metal, and asphalt, but not wood from land clearings such as stumps and brush. The percentages of each component that make up C&D waste is shown in table 4. (Forest and Wood Products Institute, 2000)

Table 4 – Components of C&D waste by percentage
(Forest and Wood Products Institute, 2000)

Component	Clean Wood	Dirty Wood	Bulky (Fluff)	Metal	Aggregate	Dirt
Percentage	21%	9%	10%	7%	27%	25%

Of these various components, it was found that about 30 percent is woody residue. Of the various waste streams analyzed in the report, C&D waste is the most likely to experience change in the future. In most New England states, fewer landfills are accepting C&D materials while at the same time the number of C&D recycling facilities has increased. C&D waste and Municipal Solid Waste (MSW) are fighting for the same landfill space, however MSW is much denser waste and there are no viable options for recycling most MSW. C&D is much bulkier and uses more space while at the same time can be dumped at a C&D facility just as easily and possibly for less money making room for incentives as the cost of C&D material disposal becomes increasingly expensive or impossible at a landfill. The total amount of woody C&D residue that could be used for biomass is 354,000 tons as seen in Table 5. (Fallon, 2002)

Table 5 – Recycled and Disposed C&D waste in 1999
(Fallon, 2000)

C&D Woody Residue	Generated Tons	Recovered Tons	Percent Recovered	Discarded tons
	404,000	50,000	12%	354,000

2.2.2 MSW Waste

MSW, also known as trash or garbage consists of items such as packaging, grass clippings, furniture, clothing, bottles, food scraps, newspapers, appliances, pallets and shipping containers. (EPA, 2008)

Table 6 – Massachusetts Annual MSW Wood Waste Generation and Recovery
(Dorn & Associates, 1998)

MSW Woody Residue	Generated (tons)	Recovered (tons)	Percent	Discarded (Tons)
	371,700	206,300	55%	165,400

MSW wood residue is composed primarily of wooden pallets and shipping containers. It is estimated that some 45-50 percent of U.S. hardwood is used for making new pallets. The primary recovery rate for pallets at recycling stations and at pallet refurbishers nationally is 55%. It is estimated that over 223.6 million pallets enter landfills yearly. Although it is estimated that the percentage of pallets recycled can be increased, the problem of contamination from chemicals and dirt make many of the pallets less desirable for older wood fired technologies. (Dorn & Associates, 1998)

2.2.3 Urban Wood Residues

Urban woody residue tends to be "clean" biomass and comes from nine general categories of contributors: (McKeever, 2003)

- Commercial tree care firms
- Municipal/County Park and Recreation Departments
- Municipal Tree care divisions
- County tree care divisions
- Electric utility power line maintenance firms
- Nurseries
- Landscapers and landscaping maintenance firms
- Excavators and land clearing firms
- Orchards

For the most part, urban residue is "clean" and is a combination of: (McKeever, 2003)

- Wood
    - Chips, logs, tops & brush, mixed wood, whole stumps, tree limbs
- Leaves
- Grass clippings

Most of the urban woody residue in the Northeast is from tree trimmings and is either managed at the point of generation or is given away and never enters the waste system. Approximately 56 percent is managed on site, 17 percent is land-filled, 12 percent is sold, 3 percent is recycled, 3 percent is burned for energy and the last 9 percent is managed in other ways. The Urban woody residue category is one that has good potential for expansion. The synergistic recycling of the waste to produce energy and saving landfill space gives incentive for companies to recycle. The summary of urban wood residue is shown in Table 7.

Table 7 – Biomass from urban wood residue
(Fallon, 2002)

	Generated (tons)	Recovered (tons)	Percent Recovered	Discarded (tons)
URBAN WOOD RESIDUE	1,049,200	755,400	72%	293,800

2.2.4 Primary Wood Manufacturer

Primary Wood Manufacturers in Massachusetts are comprised of approximately 80 stationary sawmills which prepare the raw materials. In doing so, the fresh trees are milled, debarked and classified for further use. Woody residues from sawmilling can be broken down into woodchips, sawdust, and bark. (Forest and Wood Products Institute, 2000) Table 8 shows the results of a survey conducted by the University of Massachusetts and the Forest and Wood Product Institute (F&WPI) to determine among other things, the annual wood residues from the five western counties in Massachusetts which include: Berkshire, Franklin, Hampshire, Hampden and Worcester counties.

Table 8 – Annual residues from the five western MASS counties
(Forest and Wood Products Institute, 2000)

Species	Bark (tons)	Woodchips (tons)	Sawdust (tons)	Total (tons)
Softwood	23,375	64,625	49,500	137,500
Hardwood	22,275	51,975	49,500	123,750
Total	45,650	116,600	99,000	261,250

A common way to classify wood is as hardwood or softwood. The distinction between hardwood and softwood has to do with plant reproduction. All trees reproduce by producing seeds, but the seed structure varies. Hardwood trees are angiosperms, plants that produce seeds with some sort of covering. This might be a fruit, such as an apple, or a hard shell, such as an acorn. Softwoods, on the other hand, are gymnosperms. (Merriam Webster, online) Evergreens do tend to be less dense than deciduous trees, and therefore easier to cut, while most hardwoods tend to be denser and sturdier making them more valuable. Figure 4 shows the locations of most sawmills in Massachusetts. Of the 73 sawmills shown on the map, 51 are in western counties, and therefore are included in the residues above, however at least 23 are not included in that tally. Later in the F&WPI report, based on a linear difference in quantities, Table 9 was formed to estimate the residues from primary manufacturers for the whole state making the estimated total annual residues from primary manufacturers to be 290,874 tons.

Table 9 – Estimate of total annual residues from primary manufacturers.
(Forest and Wood Products Institute, 2000)

Species	Bark (tons)	Woodchips (tons)	Sawdust (tons)	Total (tons)
Total	53,007	137,000	100,761	290,874

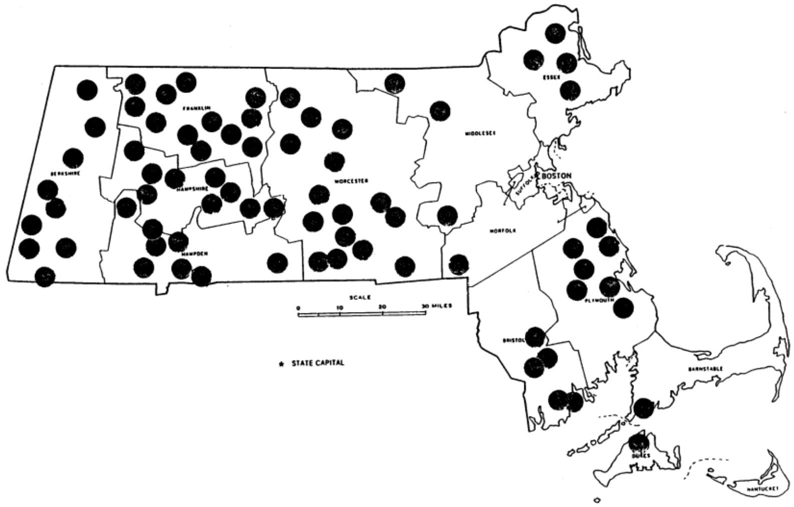

Figure 5 – Massachusetts Sawmill locations.
(Forest and Wood Products Institute, 2000)

Because of the organized conditions in industry and the cost of waste disposal, the recovery rate of biomass residues in stationary sawmills in Massachusetts is 98 percent. This means that the total available woody biomass from primary manufacturers is only about 6,000 tons annually. Currently this residue typically travels to out-of-state paper mills and other markets. Although there is very little room for expansion in the quantity recycled, it is possible that if the market for biomass increased and became more profitable than other products, much of the Primary wood manufacturer's wood waste could be used for in-state biomass. (Fallon, 2002)

2.2.5 Secondary Wood Manufacturers

Secondary Wood Manufacturers are those who produce products from the raw materials such as flooring, cabinets, boxes, furniture, windows, shipbuilders, arts and caskets. In Massachusetts, there are 816 secondary wood manufacturers whose wood residues include sawdust, sander dust, wood chips and shavings, wood flour, rippings, cut-offs and ends. Again, because of the organized conditions of the industry and the benefits of recycling biomass, the recovery rate for secondary wood manufacturers is 98 percent and there is not much room for expansion. The majority of the residues were kiln-dried with moisture contents between 8 percent and 15 percent making it excellent material for fuel. Table 10 shows the tabulated biomass from statewide secondary manufacturers for woody residue. (Forest and Wood Products Institute, 2000)

Table 10 – Woody Residue Biomass From Statewide Secondary Manufacturers
(Forest and Wood Products Institute, 2000)

Secondary Manufacturers	Generated (Tons)	Recovered (Tons)	Percent Recovered	Discarded (Tons)
	225,000	220,500	98%	4,500

2.3 Quantities of woody biomass in Massachusetts

Table 11 – Summary of Woody biomass Resources and Supply in Massachusetts.
(Fallon, 2002)

Woody Biomass Source	Amount (tons/year)
Residue Sources	
Municipal Solid Waste	523,500
Construction and Demolition Debris	404,000
Primary Wood Manufacturers – Residues	279,608
Secondary Wood Manufacturers – Residues	225,000
Urban Wood Residue	1,049,200
Subtotal	2,481,308
Unutilized Annual Net Growth in MA Forests	
Growing Stock Trees	1,484,000
Branches, Top Wood	446,000
Subtotal	1,930,000
Total	**4,411,308**

As seen in Table 11, in the State of Massachusetts, the total woody biomass available in Massachusetts is 4,411,308 tons per year. This number comes from a combination of the available residue sources and the unutilized annual net growth in Massachusetts forests.

There are several factors that could change the quantities of woody biomass in Massachusetts. The assessment of woody biomass resources is subject to change for various reasons. Sustainability is essentially a steady state that can be difficult to maintain, because there are so many different influences involved. Most concerns can be categorized as environmental or economic and both are equally important. In the long run, if the environment is not preserved, the resources will run out. At the same time, the biomass needs to be financially competitive with other fuels for society to accept it as a viable alternative. This section will discuss factors that if not dealt with could significantly harm the environment and the potential of a green power source.

- Continued fragmentation/urbanization of forests
- Economic sustainability
- Environmental sustainability

Because of the complexities of sustainability, it is difficult to define sustainability as a rule. Instead of a definition, general criteria and indicators are developed so that a range of forest activities can be assessed and their management adapted to the location. Environmental criteria are designed to evaluate health, productive capacity, biodiversity, soil, water, nutrient, and carbon budgets. Economic criteria look at levels of employment, price of wood and other forest products and social criteria.

Creating new woody biomass markets can have positive economic benefits such as: creating markets for biomass wastes; improving economic viability of thinning operations; promoting new crops to farmers who have marginal or unused farm land; creating employment in biomass production, harvesting, transport and conversion to useful energy; and providing a saleable energy product. Compared to food crops, energy crops are typically of lower value and rely heavily on low production costs.

Environmental sustainability can be broken down into three categories which include:

- Site productivity
- Biodiversity
- Greenhouse gas balances

Site productivity refers concerns about soil nutrients, organic matter, and moisture-holding capacity being depleted by intensive harvesting methods. The soil nutrient level is dependent on nitrogen and other elements which are abundant in twigs and other foliage decomposing on the ground. For general forest management this never becomes a problem, because only a small portion of the branches and tops are removed leaving sufficient biomass to create good quality soil. Furthermore, ash created from combustion of the biomass for energy can be spread on the forest floor as a fertilizer to replenish the soil. For nutrient poor-sites or short rotation tree crops, the ash should be recycled once per forest rotation to keep the soil nutritious.

The larger environmental concern with woody biomass is erosion. The protection of soil is dependent on very careful forestry practices. Much of the equipment for harvesting is very heavy. As the machinery rolls over the forest bed, there is a tendency for physical disturbance such as severe compaction or removal. Where the soil is disturbed, water flows and runoff must be managed to prevent the contamination of water bodies with excessive silt. Compaction will reduce the extent and time of root growth and is not good for a healthy forest. (Sustainable Production of Woody Biomass for Energy, 2002)

For the biomass farm, biodiversity becomes an issue. Natural forests emphasize existing biodiversity by protecting natural, unique ecosystems and habitats through balancing vegetation structure, growth stages and forest ecosystem types over time. Planned, planted forests have to focus on retaining patches or corridors of natural vegetation as part of the overall site plan. Short rotation crops have a much higher productivity requiring smaller areas that need to be intensely managed.

Woody biomass offers significant possibilities for reducing greenhouse gas emissions compared with the current emissions of fossil fuels. It is also possible for biomass to enhance carbon sequestering since short-rotation crops forests established on former agricultural land act as carbon sinks by accumulating carbon in the vegetation and soil. The KYOTO Protocol I (Sustainable Production of Woody Biomass for Energy, 2002)

3.0 Energy Sources

3.1 Wood burning

Wood burning involves combustion of woody biomass to make either heat or electricity. Generally things to consider in evaluating the sustainable quantity of wood as a fuel include:

- Dependability of fuel source
- Depletion of soil nutrients
- Local infrastructure and technology
- Transportation
- Fuel form (i.e. pellet, cord wood etc..)
- Storage
- Waste management (ash and other residues such as tar)
- The effect on other industries
- Cost

Most of these factors will apply to both small scale and large scale use of wood but may vary slightly depending on the specific use. Additionally cost is intertwined with every consideration. The dependability of the fuel source depends on the growing conditions and how mass “tree-farming” affects the land. It is possible that initially the land will produce large quantities of growth, however over time without renewing the nutrients in the soil, the production will decrease as the fertility of the land decreases. Transportation has historically been a problem for many products, however, trees are particularly heavy and dense. One of the largest difficulties in the advancement of woody biomass as an energy source, is the cost incurred in harvesting and transporting. A single 18-inch diameter tree of a given height contains the same volume as twenty-4 inch diameter trees however it is much more expensive to harvest 20 trees than 1. Often when the end use for woody biomass calls for chipped or ground material (i.e. in power plants) it is often more efficient to chip the material in the forest and haul the chips to the plant rather than hauling the unprocessed woody biomass. The problem is that the vehicles typically used to haul chips, known as chip vans cannot navigate many forest roads, which were designed for logging trucks. Hauling material in smaller vehicles is more costly; this adds to the difficulty in using the material cost effectively. (Report to chairman, 2005)

Another obstacle is the lack of local infrastructure for harvesting, transporting and processing woody biomass. This includes loggers, mills and, appropriate equipment for treating small diameter material. The general decline in logging has left areas without much of the infrastructure required to cost effectively process small to medium sized material. (Report to chairman, 2005)

The objective in removing small-diameter trees and other low/no value biomass is to use technologies that are the most economical, and to meet resource protection needs. New technology is useful when the economics can work, however some of the currently available harvesting and transporting equipment may cost as much as $500,000 and although it increases production, the large set up cost may deter some companies. This becomes important because for biomass to take hold in Massachusetts, there needs to be more harvesting, transporting and treating infrastructure, which includes more companies. (Woody Biomass Utilization Desk Guide, 2007)

3.1.1 Industrial electrical production

For the conversion of woody biomass to electrical energy, the process begins with harvesting and ends with an export of power to the electric grid as seen in the Figure 6.

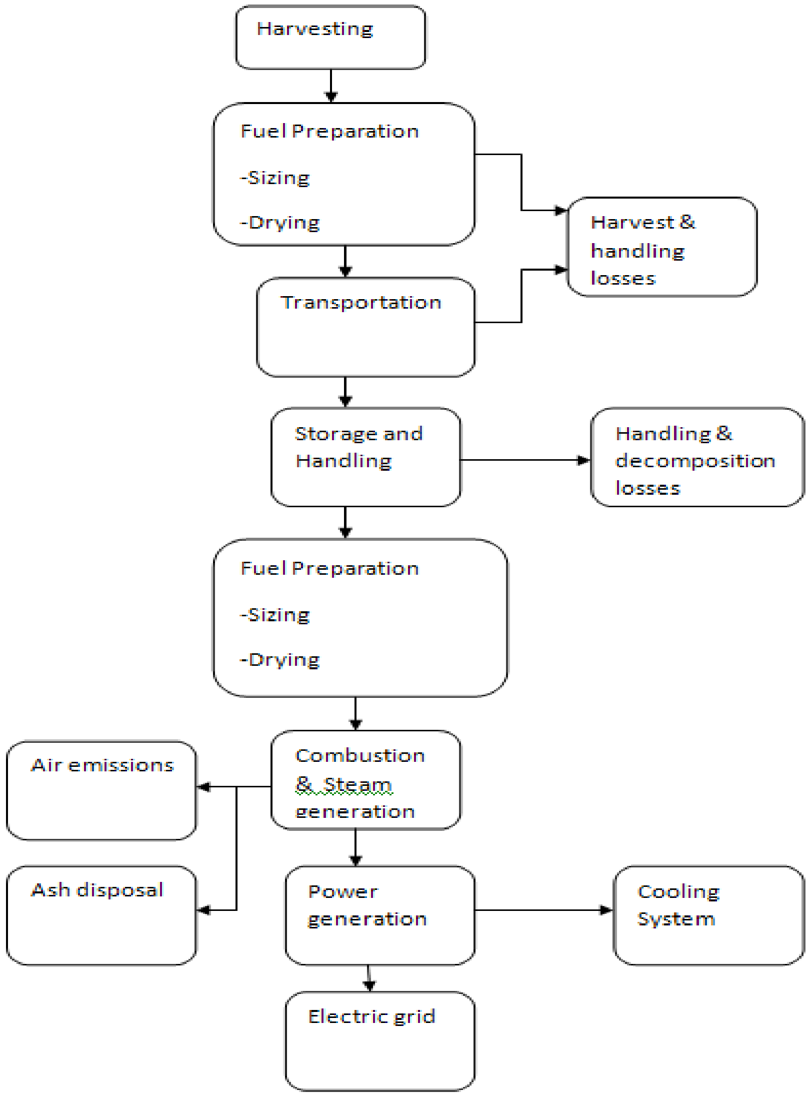

Figure 6 – Process diagram from harvest to electrical production
(Perlack, 1995)

3.1.1.1 Technologies

There are two general applications for the conversion of woody biomass to electric energy. The first is the stand-alone, grid-connected power plant using woody biomass to power a turbine. The second application is for co-firing at a fossil-fired electric generation facility. Although, there have been many technological advances in recent years such as circulating fluidized-bed boilers and combined cycle cogeneration , the conversion technology of choice is still the steam turbine cycle (Rankine cycle). (Background Info., 2001)

Generating electricity from biomass with a conventional steam turbine is physically very similar to generation with coal, the only differences being found in handling of the material, preparation, and emissions control. The problem is not found in the process, but in the fuel itself. The lower mass density and the heating value of wood compared to coal means that the biomass system will require more fuel to produce the same quantity of energy, meaning extra costs for fuel handling and larger boilers. The tradeoff between the costs of handling extra fuel and having larger boilers are offset by the simpler emissions controls compared with coal. In the end, the installation costs ($/kWh) for the biomass system will be approximately the same as for a coal fired power plant.

To produce electricity using the steam turbine, the wood has to be prepared by separating it by size and possibly drying it. Next, the wood is burned in a boiler which heats and pressurizes water. The water turns to steam which becomes pressurized and expands pushing a turbine. The turbine connects to a generator and spins it creating electricity. If process heat is to be produced in addition to electricity, a back-pressure turbine is used which after producing electricity takes some of the hot steam for heating purposes. The typical efficiency of a direct-fired biomass facility is about 20-24 percent. Co-firing woody biomass with coal is generally used to reduce the SO_2 emissions. The economic benefit is great if the systems are already set up, the fuel is dependable as coal can always be used in replacement. Additionally, because of the reduced SO_2, the plants may not have to invest in new scrubbers. There are some small changes which would have to be made for the co-firing to run smoothly, however the benefits are great and the transition from fossil fuels to renewable energy can be made smoothly. Because coal-fired power plants generally are more efficient than direct-fired biomass, the efficiency of converting the biomass to electricity is between 33-37 percent. There are several technologies and processes that if added to the steam turbine set up can increase efficiency. The first is to dry the biomass using the leftover heated steam from the turbine. Preheated waste air is used to dry the wood stacked in a large building for 30 days before being conveyed to a boiler and burned. Allowing the wasted heat to dry the green wood can result in a furnace efficiency approaching 87% with a net plant efficiency reaching 35%. (Biomass Energy, 2008)

3.1.1.2 Estimated output

Woody biomass has an energy density of slightly less than 20 GJ/dry ton and it was found that Massachusetts has 4,411,308 tons of renewable woody biomass produced every year. Unfortunately, the burned wood is not usually completely dry. When wood is cut, it is at approximately 50 % water and when wood is considered seasoned or dry, it is at approximately 17% water. Wood that has not been seasoned has approximately 15 GJ/ton. (Perlack, 1995) When the 15 GJ/ton is multiplied by the 4,411,308 tons of biomass, 67,500,000 GJ of power are produced. Again, the number is not straightforward, because there is some energy from fossil fuels used to create the electrical output from the woody biomass. For wood combustion, there is approximately one unit of fossil fuels used for every 25-50 units produced. (IEA, 2008) This means that for every 25-50 joules of energy produced from woody biomass, only one joule of fossil fuel energy had to be used. This means that the 67,500,000 GJ of power is more like 65,625,000 GJ of power per year, which is 4,051 KWh per ton of wood. Again, if the 4,051 KWh/ton is multiplied by 4,411,308 tons of wood, 18,229,500 KWh/year can be produced by burning wood at electric power plants in Massachusetts annually. Since Massachusetts uses approximately 51,000,000 KWh/year, (Mass Energy Statistics, 2008) biomass can potentially replace up to 35% of the state's current electrical demand.

3.1.2 Private Home Heating

Before the 20th century, 90% of Americans burned wood to heat their homes. As fossil fuel use became more dominant, the use of wood fuel dropped reaching as low as 1% by 1970. During the energy crisis in the 1970s petroleum products including gas and oil became rationed and people began reevaluating wood as a home heating source. (Wood and Pellet Heating, 2005)

3.1.2.1 Technologies

Today, there are several options for homeowners who would like to heat with wood. The types of wood and pellet burning appliances include: fireplace inserts; catalytic wood stoves, advanced combustion woodstoves and centralized wood burning boilers; masonry heaters; and pellet fuel appliances. (Wood and Pellet Heating, 2005)

Traditional open masonry fireplaces are not considered heating devices as they draw in up to 300 cubic feet per minute of heated home air for the combustion process and operate at about 10 percent efficiency. High efficiency fireplace inserts are essentially like woodstoves inside a fireplace. A well fitted insert can be as efficient as a wood stove. (Wood and Pellet Heating, 2005)

Wood stoves are the most common way to burn wood and with catalytic stoves and inserts, they are 70-80 percent efficient. In catalytic combustion the smoky exhaust is passed through a coated ceramic honeycomb inside the stove where the smoke gases and particles ignite and burn.(Wood Stoves, 2007) Advanced combustion woodstoves have several components that help them burn at temperatures up to 1100ºF, which is hot enough to burn combustible gases. New advanced combustion stoves have efficiencies of 60-72 percent. Centralized wood burning boilers have been improved over time and modern ones use wood gasification technology. This burns the wood fuel and associated combustible gases making the system up to 80% efficient. (Wood and Pellet Heating, 2005)

Masonry heaters produce more heat and less pollution than any other wood or pellet burning system. The heaters are lined with fire brick or other material that can withstand temperatures up to 2,000ºF. Small fires, when built a couple times per day, release heated gasses. These gases heat the masonry interior and in turn slowly release the heat over a long period of time. Masonry heater systems can reach an efficiency of 90%. Pellet fired systems burn small pellets that look similar to rabbit feed. The pellets are made from compacted sawdust, wood chips, bark, agricultural crop waste, waste paper, and other organic materials. Pellet stoves are convenient to operate and have efficiency ratings between 78-85%. . (Wood and Pellet Heating, 2005)

3.1.2.2 Estimated output

The Smithers method for calculating the number of cords of wood required to heat a house uses energy equivalents and estimated efficiencies of fuel production. Using Tables 12 and 13, and the equation below, one is able to determine the equivalent required chords to heat their house. (Home heating with wood, 2002)

Table 12 – Energy Efficiency Values
(Home heating with Wood, 2002)

Eb	Heater	Ew	Wood Heater
0.65	Oil Furnace	0.10	Fireplace
0.70	Gas Furnace	0.25	Improved Fireplace
1.00	Electric	0.30	Non-airtight Stove
0.65	LP Gas	0.50	Airtight Stove
		0.60	Wood Furnace
		0.65	Airtight stove with Catalytic Combustor

Table 13 – Various energy equivalents to a cord of wood.
(Home Heating with Wood, 2002)

One cord of average dry wood equals = W =	150 gallons No. 2 fuel oil
	230 gallons of LP gas
	21,000 cubic feet of natural gas
	6,158 KWh electricity

$$Cords = \frac{B * E_b}{W * E_w}$$

Equation 1(Home Heating with Wood, 2002)

In a 1997 Survey, of the 102 million homes in the United States approximately 1 in 10 used oil for space and water heating. About 7.2 billion gallons of oil were consumed in 1997 for residential use which to the 10 million American who use the fuel averaged to 730 gallons each per year. (Dept. Energy, 2002) If 730 gallons is imputed into equation1 as follows it will equate to 5.27 cords of wood per home per year. In the equation below, an efficiency of 60 percent is used from Table 12 because the wood furnace is the most commonly used form of a home wood heating system.

$$Cords = \frac{730\,gallons * 65\%efficient}{\left(\frac{150\,gallons\#2oil}{1cordwood}\right) * 60\%efficient} = 5.27\,cords$$

This means that for a home that would generally use 730 gallons of oil throughout the course of the year, the equivalent energy in wood would require about 5.3 cords. The average weight of wood per green cord is 3000 lbs or 1.5 tons. (DeWald, 2005) If 5.27 cords is required at 1.5 tons each that is 7.9 tons per home per year. As previously concluded, the total available woody biomass is 4,411,308 tons of green waste and growth. If that value is divided by the 7.9 tons per home. It can be concluded that 558,393 homes could be heated from the woody biomass available in Massachusetts. Since there are 2,708,986 homes in Massachusetts (Federal Statistics, 2008) 558,393 homes would be approximately 20% of Massachusetts homes. It should be remembered that these numbers are based on an assumption of converting the average 730 gallons of oil used to required cords of wood. This means that the results of these estimates assume that not only heat but also hot water would be provided by the wood since the 730 gallons included hot water heating.

3.2 Liquid Fuels from Wood

Wood is a source of lignocellulosic biomass which consists of lignin, cellulose and hemicellulose. Cellulose and hemicelluloses are complex carbohydrates made up of sugars held together in long chains called polysaccharides. Breaking these chains down into fermentable sugars which are then capable of being converted into different types of liquid fuels is the major obstacle facing the biorefining industry. The fuels of interest are ethanol, methanol and biodiesel; all of which can be useful in the transportation market. This makes wood, among other sources of cellulose very appealing for the future of our Commonwealth's energy security. Ethanol and methanol are the fuels of focus because of their interchangeability with the fossil fuels already used to power our vehicles.

3.2.1 Legislation and Incentives

The Massachusetts state government has long realized the need for biofuels infrastructure in our Commonwealth and subsequently, their power to spur the development of alternative energy sources through legislation. In 1996, Massachusetts Governor William F. Weld ordered the Department of Procurement and General Services (DPGS), the Division of Energy Resources (DOER), the Department of Environmental Protection (DEP), and the Executive Office of Transportation and Construction (EOTC) jointly to develop and implement a plan. The plan was to accomplish the minimum alternative fuel vehicle purchase requirements as outlined by executive order number 388. According to this executive order, by the year 2001, at least 75% of non excluded vehicles (as determined pursuant to 10 C.F .R. Part 490) purchased by DPGS shall be the cleanest alternative fuel vehicles (AFV) available and practical. At least 10% of the total non-excluded vehicles purchased by DPGS shall be Zero Emission Vehicles. (Weld, 1996)

The next major piece of biofuel legislation did not occur until 2002 when the Massachusetts DOER issued the Renewable Energy Portfolio Standard (RPS). The purpose of this standard was to help diversify the state's electricity supply portfolio, stabilize rates, increase energy security, improve environmental quality, and invigorate the clean energy industry. The RPS distinguishes between old and New Renewable Generation Units (NRGU). The following fall under the category of NRGUs:

> “Solar photovoltaic or solar thermal electric energy, Wind energy, Ocean thermal, wave, or tidal energy, Landfill methane gas and anaerobic digester gas, provided that the fuel is directly supplied to the generating unit rather than conveyed through conventional delivery networks for natural gas Low-emissions, advanced biomass power conversion technologies using an eligible biomass fuel, Fuel cells using an "eligible biomass fuel," landfill or anaerobic digester methane gas, hydrogen derived from such fuels, or hydrogen derived using the electrical output of a qualified renewable generation unit. (Fuel cells using hydrogen derived from other fuels or from electricity produced by nonrenewable units are ineligible).” (Black, 2008)

In August 2006, the Massachusetts Executive Office of Administration and Finance (A&F) issued Bulletin 13, “Establishment of Minimum Requirements for Bio-

Fuel Usage in State Vehicles and Buildings by Executive Agencies". The purpose of Bulletin 13 is to aid the transition from fossil fuels to biofuels, starting with the state building and transportation sector. A&F partnered up with the Division of Energy Resources (DOER) to set minimum biofuels usage requirements by all state vehicles. Each year, A&F and DOER will set new minimum percentage requirements for E85 usage in state flex-fuel vehicles. (Trimarco, 2006)

As seen in Figure 7, state owned and operated vehicles used 4,055,967 gallons of gasoline and 21,698,997 gallons of Diesel in the fiscal year 2002. This consumption of diesel and gasoline amounted to 16.21% and 2.65% respectively of the total CO2 emissions given off by the state building and transportation sectors. (Mass. Greenhouse, 2004) This amount of Green House Gas (GHG) is why Bulletin 13 is focused on biodiesel and cellulosic ethanol. The Administration's commitment to long-term cost containment, energy efficiency, improved public health and natural resource conservation, is the driving force behind phasing in the use of biofuels in all executive agency vehicle fleets and #2 heating oil boilers to replace petroleum-based fuels.

	Transportation Fuel Use						
Agency	At the Pump CNG (gallons)	MBTA electricity (kWh)	At the Pump Ethanol (gal)	Propane (gallons)	At the Pump Gasahol (Gallons)	Diesel (Gallons)	Gasoline (Gallons)
Conversion Factor	*1.21*	*0.93*	*12.54*	*12.70*	*19.36*	*22.38*	*19.56*
Consumption	20,861	397,632,338	526	60,257	5,900	21,698,997	4,055,967
Units	gallons	kWh	gal	gallons	gallons	gallons	gallons
CO_2 tons	11	167,709	3	347	52	220,237	35,979
% of total CO_2 by fuel	0.001%	12.35%	0.000%	0.03%	0.004%	16.21%	2.65%
Total tons of CO2 by sector	424,339						
% of Total CO2 by sector	31.2%						
% of sector CO2 by fuel	0.00%	39.52%	0.00%	0.08%	0.01%	51.90%	8.48%

Figure 7 – Fuel Consumption by Massachusetts state Transportation sector
(Mass. Greenhouse, 2004)

The future is very bright for the implementation of biofuels infrastructure in Massachusetts. Governor Deval Patrick, Senate President Therese Murray, and House Speaker Salvatore DiMasi announced on November 5, 2007 that they are jointly backing legislation which promotes the advancement of biofuels as a way to reduce dependence on foreign oil, capture clean-air benefits, and capitalize on clean-fuel research for economic growth and jobs. (Patrick, 2007)

> "This legislation requires a minimum percentage of biodiesel as a component of diesel fuel sold in the Commonwealth. This starts at 2% in 2010 and ramps up to 5% by 2013. (It also) requires a minimum percentage of bioheat as a component of heating oil sold in the Commonwealth. This starts at 2% in 2010 and ramps up to 5% by 2013. (Lastly, it) exempts cellulosic ethanol used in transportation fuel from state gasoline excise tax." (Patrick, 2007)

Research and Development (R&D) in new biofuels production technologies and fuel delivery infrastructure is provided by the necessary incentive needed from the legislation previously mentioned. The benefits of reaching these goals are extensive. "The gas-tax incentive for cellulosic ethanol is projected to create 3,000 new jobs in Massachusetts and pump $320 million into the economy as the advanced ethanol (cellulosic ethanol) is brought to market." (Patrick, 2007) Along with this economic increase will come a decline in greenhouse gas emissions and would yield substantial energy security due to the localization of our energy resources. These initiatives put in place by the Massachusetts state government will propel the Commonwealth to the forefront of biofuels infrastructure and commercialization.

3.2.2 Ethanol from Woody Biomass

Fossil Energy Ratio (FER) = Energy in fuel/Fossil Energy input

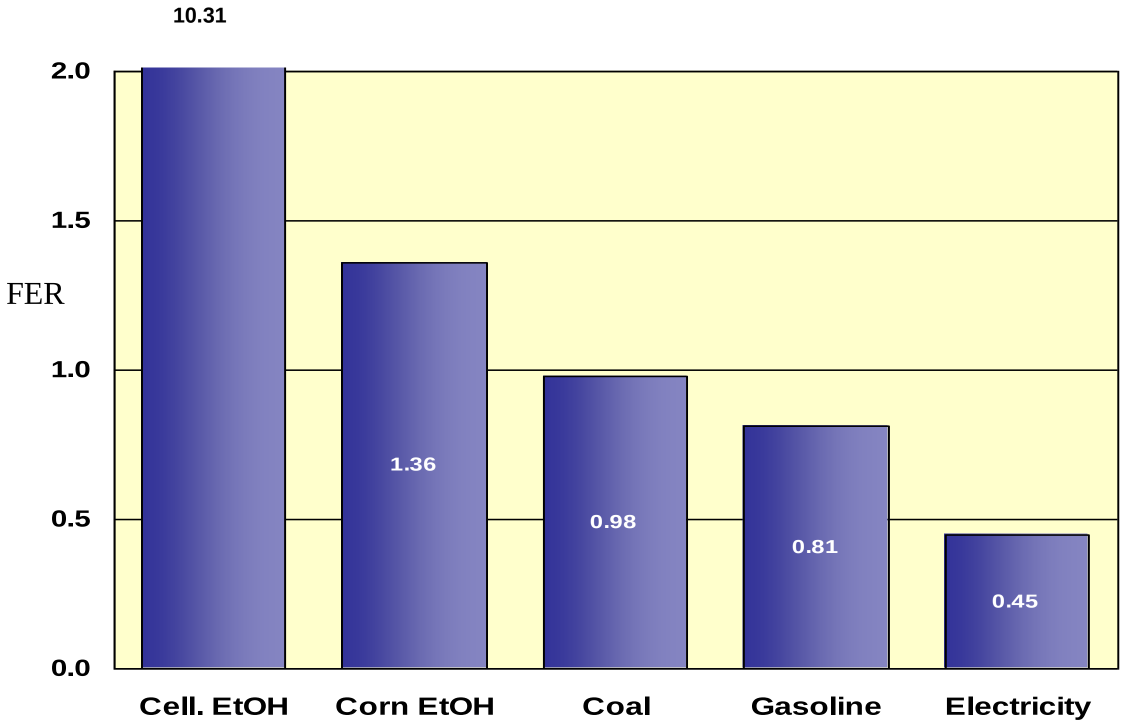

Figure 8 – Ratio of the Energy in Fuels to the Fossil energy input

(Energy and GHG, 2005)

3.2.2.1 Introduction

Ethanol or ethyl alcohol (C_2H_5OH) is a clear, combustible liquid that can be blended with gasoline to fuel internal combustion engines in automobiles. But unlike gasoline, ethanol contains 35% oxygen which allows for it to be burned with a significantly lower amount of particulate and NOx emissions. (Thomson, 2006) Figure 8 clearly shows how that cellulosic ethanol is much more energy efficient and environmentally friendly overall than any of the other proposed energy sources. When added directly to gasoline or used to produce ethyl tertiary butyl ether (ETBE) for gasoline blends, ethanol improves combustion and reduces tailpipe carbon monoxide and hydrocarbon emissions that contribute to ozone formation and smog. (Wyman,1996)

Each of the different processes outlined in this section are developing technologies with a lot of room for improvement in cost effectiveness and efficiencies.

3.2.2.2 Processes

There is a wide array of different methods available to produce ethanol from wood. For the most part, these processes can be broken down into the following two categories: Thermochemical and Biochemical conversion processes, which include fermentation, gasification, pyrolysis, and physiochemical processes.

3.2.2.2.1 Biochemical Conversion Processes

The first step in each one of these processes is to break down the woody biomass by chipping and grinding it down to size and then breaking down the lignocellulosic material or polysaccharide molecules into soluble sugars known as saccharides. This is done through hydrolysis, saccharification or other thermochemical means. (Bergman, 2008) These simple sugars are then used as feedstock for the production of ethanol through microbial fermentation. As seen in Figure 9, simultaneous saccharification and fermentation (SSF), consolidates these two steps into one efficient and cost effective step, producing ethanol directly from pretreated lignocellulose. SSF is a very promising method due to its ability to improve hydrolysis rates, yields, and product concentrations compared to separate hydrolysis and fermentation (SHF) systems. (Wright, 1987)

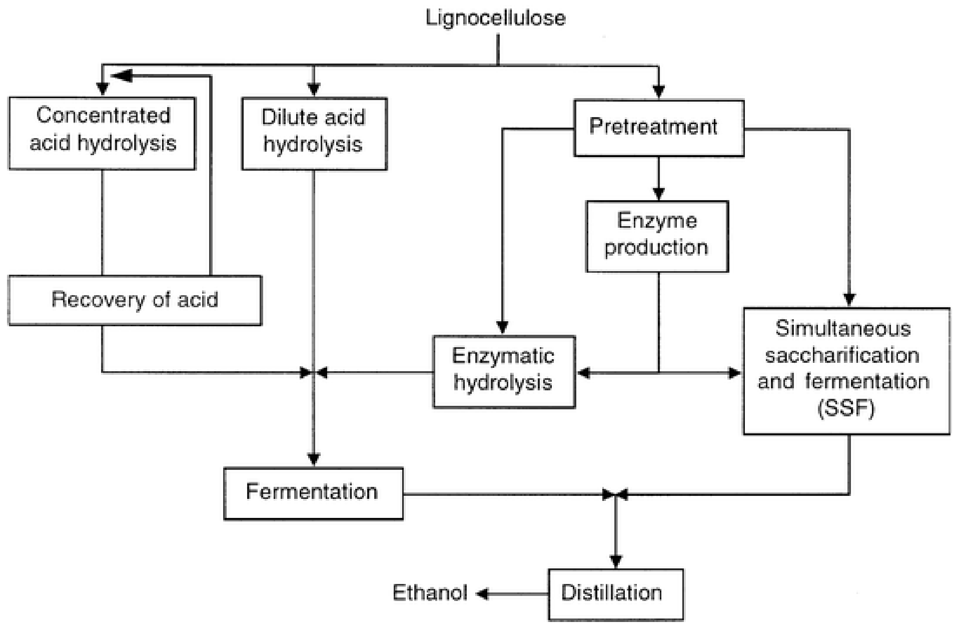

Figure 9 – Production of ethanol from lignocellulosic materials
(Zacchi, 2002)

The three main methods of hydrolysis are dilute acid, concentrated acid, and enzymatic hydrolysis. Dilute acid hydrolysis utilizes hydrochloric acid to break the crystalline structure of the lignocellulosic material to expose the soluble sugars. This process operates at high temperatures and pressures and has a reaction time of only a few minutes which allows for continuous processing. The biggest disadvantage to this method is the low sugar yield of only about 50% recovery efficiency. This low recovery efficiency is due to the continuous processing which causes sugars to degrade into other chemicals that can be harmful to the micro-organisms found in the fermentation step. (Thomson, 2006)

The concentrated acid method, on the other hand, has a much longer total processing time but a much higher recovery efficiency of up to 90%. Among biochemical conversion processes concentrated acid hydrolysis is the most promising for small startup companies that will undoubtedly rise from the tax incentives associated with the production and consumption of cellulosic ethanol in Massachusetts.

The third method of producing the sugars necessary for fermentation is known as enzymatic hydrolysis. In this process, pre-treatment is necessary to break down the crystalline structure of the lignocellulosic material, isolating the cellulose away from the lignin in the cell walls for hydrolysis. The cellulose is then hydrolyzed with cellulase enzymes. (Zacchi, 2002) Due to the enzymes' efficiency at breaking down cellulose, enzymatic hydrolysis will likely receive more Massachusetts state research and development funding than the previous two lignocellulose conversion options.

The next step in each of these biochemical conversion options, microbial fermentation, is the process by which microorganisms use 6-carbon carbohydrates sugars such as glucose for food. Ethanol is produced in the metabolic process along with other by-products. (Thomson, 2006) Fermentation is already a highly researched and tested technology and the infrastructure in Massachusetts is going to make it relatively easy to transition to biochemical fermentation paired with enzymatic or acid hydrolysis.

A more recent and cutting edge method utilized in ethanol recovery is the use of microorganisms to produce ethanol from woody biomass. One of the most promising new methods involves the metabolism of a newly discovered microorganism known as the "Q microbe" Which was discovered by Professor Susan Leschine of the Microbiology department at the University of Massachusetts. This microbe feeds off of the broken down and hydrolyzed cellulose, producing ethanol and other byproducts of digestion. If they are successful in efficiently up scaling this technology, it has the potential to be the future of biomass conversion in our Commonwealth. (Leschine, 2007)

3.2.2.2.2 Thermochemical Conversion Processes

Pyrolysis and gasification are the two main thermochemical ethanol conversion processes. When the equivalence ratio, which is defined as the ratio of the actual air-fuel ratio to the stoichiometric air-fuel ratio, equals one, complete combustion theoretically occurs. At an equivalence ratio of zero, no oxygen is present and fuel pyrolysis occurs. Pyrolysis produces a bio-oil that can be further refined to a hydrocarbon product. The decomposition occurs at lower temperatures than the gasification processes, and produces liquid oil instead of a synthesis gas. The bio-oil then needs to be further refined before being converted into ethanol.

Gasification is a form of incomplete combustion which occurs as the amount of oxygen is decreased. This occurs between the two extremes of combustion and pyrolysis. (Black, 2008) This syngas or producer gas can then be converted to ethanol through chemical synthesis.

3.2.2.3 Impact and Feasibility

The U.S. Energy Policy Act of 2005 requires that 250 million gallons of the renewable fuel consumed from 2013 and beyond be cellulosic ethanol. The act considers any fuel that "is derived from any lingocellulosic or hemicellulosic matter that is available on a renewable or recurring basis including dedicated energy crops and trees, wood and wood residues, plants, grasses, agricultural residues, fibers, animal wastes, and other waste materials and municipal solid waste." (Regulatory Impact, 2007) This act alone provides a platform for cellulosic ethanol to replace fossil fuels as the main fuel within ten years. The implementation of bioethanol into the transportation market could greatly decrease the amount of greenhouse gases emitted into the atmosphere compared to the amount of emissions produced by fossil fuel vehicles today.

There are multiple reasons why bioethanol would be better as a fuel than gasoline for the Commonwealth of Massachusetts. One reason is the decrease in emissions that ethanol presents compared to gasoline. Another positive attribute of ethanol compared to fossil fuels is its limited toxicity to the environment. Bioethanol is additionally beneficial because of the shorter transportation distance compared to that of oil and in the event of a spill the biodegradable fuel will cause less harm to the wildlife in the environment.

Cellulosic ethanol is also a better choice for Massachusetts than corn ethanol because of the abundance of forest resources available around the Commonwealth compared to our corn harvest. The traditional method of producing ethanol from grains such as corn and wheat sorghum is fermentation, which commonly utilizes some type of fossil fuel to heat the boilers in the distillation columns and power the process. New lignocellulosic biomass conversion processes can be mostly run on the otherwise wasted lignin byproduct, saving money, energy and the environment. (Bergman, 2008)

These are just a few examples of how the implementation of bioethanol into our energy market would improve the emissions of greenhouse gases, improve our environmental footprint, and alleviate our dependence on fossil fuels. The enforcement of Governor Patrick's biofuels initiative will make the transition from old fossil fuel infrastructure to new ethanol infrastructure much smoother. None of the new technologies talked about here are capable of bringing ethanol to market by themselves. There will need to be a variety of different startup companies, each employing their own proprietary variation of these processes in order for this initiative to succeed.

There are 4,411,308 tons per year of woody biomass currently available in the state of Massachusetts for various forms of energy production. Assuming that all of the available wood was converted to ethanol and given that 109.04 gallons of ethanol can be produced from one ton of dry wood using dilute acid hydrolysis, 481,009,024 gallons could be sustainably produced from the available woody biomass in the state of Massachusetts in one year. 2,109,500,000 gallons of gasoline were consumed in Massachusetts, 441,100,000 gallons of methanol and 480,800,000 gallons of ethanol. (Table F1: Motor Gasoline Consumption, Price, and Expenditure Estimates by Sector, 2005) Between the ethanol already produced in Massachusetts and the cellulosic ethanol capable of being produced, a total of about 961,809,024 gallons of ethanol could go towards the replacement of fossil fuels. This number amounts to almost half of the total gasoline consumed in our Commonwealth in one year. In the year 2001, there were 5,140,532 total gasoline and diesel vehicles on the road in Massachusetts, with 3,513,020 of those vehicles being automobiles.(FHWA, 2003) Let's now assume all of the 3,513,020 automobiles were gasoline powered and the 2,109,500,000 gallons of gasoline were used entirely by those vehicles. In this scenario, our woody biomass reserves would be capable of replacing about half of the total gasoline consumed and thereby power about half of the automobiles on the road; this equates to somewhere in the region of 1,756,510 vehicles which could be run on our aforementioned ethanol reserves.

In fulfillment of requirements set forth in Bulletin 13, Massachusetts state vehicles will have a need for cellulosic ethanol availability around the Commonwealth. The advancement of this infrastructure will be helped along by the tax incentives offered in this new biofuels initiative. We then deduce the required amount of ethanol needed to offset fossil fuel consumption in Massachusetts state owned vehicles from Figure 7. There was a total of 4,055,967 gallons of gasoline, 526 gallons of ethanol and 5,900 gallons of gasohol used by Massachusetts state owned vehicles in the fiscal year of 2004. (Mass. Greenhouse, 2004) This shows a total need of 4,062,393 gallons of ethanol if the state fleet was fully comprised of E100 compatible AFVs. If the state fleet was made up of only E85 compatible vehicles, there would be a total need of 3,453,034 gallons. And considering we are theoretically capable of producing 481,009,024 gallons of ethanol from Massachusetts woody biomass, there is much more than enough wood resources available to fulfill the biofuel demand ~~for~~ the executive branch of the Commonwealth now presents due to Bulletin 13. (Conversion, 2008) The obstacle that now needs to be overcome is finding an efficient and economical way to produce the ethanol and get it to market. (Regulatory Impact, 2008)

3.2.3 Methanol from Woody Biomass

3.2.3.1 Introduction

In the State of Massachusetts, methanol is a less commonly used fuel compared to both ethanol and biodiesel. Methanol is also known as “wood alcohol” because it is mostly produced from wood products. Wood alcohol, or methanol, was a popular fuel during the 1920’s. Methanol was attained as a byproduct of charcoal manufacture through destructive distillation. Now methanol is produced using wood and coal as feedstocks, through gasification. After the biomass is broken down and pretreated, it is then gasified in the absence of oxygen to form syngas. The syngas is then converted to methanol. The conversion of syngas to methanol is similar to the process that is used to attain methanol from natural gas. One main advantage to the production of methanol is the flexibility of feedstocks which can be utilized in its processing; it can be produced from all wood components, including components such as lignin. Methanol also can be made from wood at higher yields than ethanol due to its feedstock flexibility.

3.2.3.2 Processes

Gasification, which is described in section 3.2.2.2.2, is the process that is currently used to recover methanol from woody biomass. Once syngas is recovered it can then be made into methanol. An example of a typical reactor can be seen in Figure 10 below.

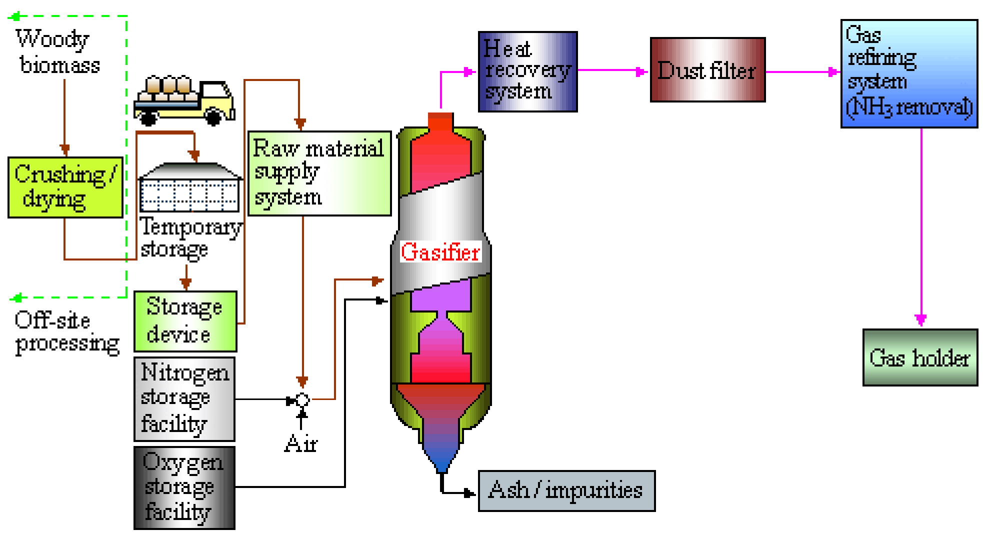

Figure 10 – Overview of gasification
(CHUBU electric Co., 2006)

3.2.3.3 Feasibility:

Methanol can also be used in the production of bio-diesel. The process of producing bio-diesel with methanol is called transesterification. With this in mind, the Commonwealth of Massachusetts has made bio-diesel available for purchase on State Contract number ENE23. Since 2000, bio-diesel has been available for use in certain state operating vehicles on a voluntary basis. Massachusetts would like to continue the use of bio-diesel in state vehicles, so beginning in the 2008 fiscal year Massachusetts is making it mandatory that a minimum of 5% bio-diesel be used in all off and on road state vehicles. The next step for Massachusetts' bio-diesel is to increase the minimum bio-diesel usage to 15% by the 2010 fiscal year. (Trimarco, 2006)

Although methanol is cheaper than ethanol and safer because it is less-flammable, ethanol is the more viable resource for the state of Massachusetts given the current technologies. Reasons why ethanol is more desirable than methanol include: the fact that methanol is more corrosive, ethanol is less chemically toxic, and methanol has a lower energy density thus making it less efficient. For these reasons, Massachusetts should try to utilize ethanol more, rather than methanol.

3.2.3.4 Estimated Output:

Using the gasification process in Massachusetts and in the rest of the U.S., it is possible to achieve approximately 100 gallons of methanol per ton of biomass feed. (Syntec Biofuel Inc, 2008) One gallon of methanol can produce approximately 62,800 Btu's, which also approximately equal to 1,840 KWh. Referring to Table 11; it shows that the state of Massachusetts is capable of producing 4,411,308 tons of sustainable biomass per year. With this amount of biomass, it is possible to produce 441,130,800 gallons of methanol per year. In a report for the RIRDC/Land & Water Australia/FWPRDC/MDBC Joint Venture Agro forestry Program, done by Enecon Pty Ltd in November of 2002, there were estimates of the wood alcohols taken with green tons, rather than dry tons, in Australia. With 12 million green tons per year it would be possible to achieve 924,602,183 gallons of alcohols per year, which gives approximately 77.05 gallons per green ton. With 35 million green tons per year it would be possible to achieve 2,773,806,549 gallons of alcohols per year (79.25 gallons per green ton), and lastly with 70 million green tones per year it would be possible to achieve 5,547,613,099 gallons of alcohols per year (79.25 gallons per green ton). (Schuck, 2002) This gives us an average value of 78.52 gallons of methanol produced per green ton. As we can see, the amount of methanol recovered from 1 green ton is approximately 21 gallons less than what is recovered from 1 dry ton.

4.0 Comparison of Energy Sources

Wood burning produces 65,625,000 GJ of power per year which is 4051 KWh per ton of wood. If the 4051 KWh per ton of wood is multiplied by 4,411,000 tons of wood per year, the result is 17,870,000 KWh per year could be produced by burning wood at electric power plants in Massachusetts annually. Since Massachusetts uses approximately 51,000,000 KWh/year, (Mass Energy Statistics, 2008) biomass can potentially replace up to 35% of the state's current electrical demand.

Next, we can find the total amount of methanol which can be produced from our wood reserves; knowing the state of Massachusetts is capable of producing 4,411,000 tons of biomass per year. Using the gasification process in Massachusetts, it is possible to achieve about 100 gallons of methanol per ton of biomass feed. Assuming that all of the available wood was converted to methanol it is possible to produce 441,100,000 gallons of methanol per year.

Annually there is a total of 68,048 thousand barrels of motor gasoline consumed by the Commonwealth of Massachusetts (Massachusetts State Energy Profile, 2008), which means 2,109,488,000 US gallons. Knowing how many gallons the Commonwealth of Massachusetts consumes annually, and that there are 4,411,000 tons per year of woody biomass currently available in the state of Massachusetts for various forms of energy production. We can now deduce that 480,800,000 gallons could be produced from the available woody biomass in the state of Massachusetts in one year given that 109.0 gallons of ethanol can be produced from one ton of dry wood and that all of the available wood was converted to ethanol, Our woody biomass reserves are capable of replacing about half of the total gasoline consumed and thereby power about half of the automobiles on Massachusetts roads; this equates to about 1,756,510 vehicles which could be run on cellulosic ethanol produced in our own Commonwealth.

Table 14 – Summary of Bio Fuels Energy Impact Annually[2]

Fuel Types	Gross (Btu/gal)	Net (Btu/gal)	Gallons Produced	Total Btu (trillion)	Percent
Gasoline	125,000	115,400	2,109,500,000	243.436	100.00
Methanol	64,600	56,560	441,100,000	24.949	10.25
Ethanol	84,600	75,670	480,800,000	36.382	14.95

5.0 Conclusions

Woody biomass comes from various sources including annual net growths and residue sources. These resources total 4,411,000 tons of green woody biomass available for sustainable harvesting per year for the State of Massachusetts. Theoretically, if all of that biomass material were to go to one specific type of energy source, we would be able to attain one of the following:

- 18,229,500 KWh of electricity per year
- 558,393 homes heated with wood stoves per year
- 480,800,000 gallons of ethanol per year
- 441,100, 000 gallons of methanol per year

Woody biomass will play a significant role in the future of the energy market in various forms; however it is difficult to pinpoint the best technology for harnessing the energy of biomass. Each of the energy sources produced from wood can be compared based on the amount of projected Btu's harvested per year. In this case, ethanol leads with the highest energy density followed by methanol, then wood burning. Although, if the price of home heating oil continues to increase; it may be beneficial for the homeowners of Massachusetts to install woodstoves. Not only does ethanol have the highest energy density among our various energy outlets, but it also is the most promising for implementation into the Massachusetts energy market. The Massachusetts state legislation agrees with this stance; this can be shown through the recent tax incentives put in place for use of cellulosic ethanol. This incentive will lead to increased R&D funding,

[2] The heating values for both the gross and net (Btu/gal) came from "Table B.4 Heat Content for Various Fuels" in work cited. The rest of the values are cited earlier in the report. Also, please note that all values have been rounded to the fourth significant figure.

which should eventually increase the efficiency of the ethanol recovery processes thereby improving the economic viability of the fuel. There are several options for which these energy forms could be utilized and several combinations of energy use which are a step in the direction of long-term sustainability for the Commonwealth of Massachusetts.

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