NATURAL CAPITAL INITIATIVE AT MANOMET REPORT

BIOMASS SUSTAINABILITY AND CARBON POLICY STUDY

CHAPTER 2

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CHAPTER 2
TECHNOLOGY PATHWAYS

2.1 INTRODUCTION TO TECHNOLOGY OPTIONS

Biomass in various forms can be used for a range of energy options, through a variety of technologies, to achieve various end purposes. In this chapter, we are looking at several pathways to give the reader an understanding of this range, but also to inform and model potential demand for fuel supply in the future (Chapter 3), and to understand the carbon implications for these choices (Chapter 6). This assessment looks exclusively at the use of existing low-grade forest resources in Massachusetts and surrounding counties in neighboring states, as opposed to agricultural crops or residues or plantation trees and crops which can also provide biomass for energy. Sources of non-forest based biomass, such as wood waste from construction debris, or other sources sometimes considered as biomass, such as municipal waste, were not considered.

With respect to the forest's low-grade wood resource potentially used for energy, the end products can be solid—such as cordwood, wood chips, or wood pellets—liquid, such as pyrolysis oil or cellulosic ethanol, or gas—synthetic or producer gas made through "gasification" and "bio-char" technologies. Finally, the end uses can range from residential to industrial applications, and fall into three general categories: electricity power production, thermal applications for heating (and cooling), or emerging technologies such as cellulosic ethanol or gasification. Between the first two categories, is combined heat and power (CHP), which in turn can be thermally led (optimizing heat production with some electricity produced) or electricity-led (sizing the plant for optimal electricity production and using some of the heat).

Some of these technologies and applications are well established and have been in place for years and others are pre-commercial or still under development. In the sections that follow, we describe two main currently available applications for electricity and thermal production, with CHP discussed in a subsequent section. This discussion focuses on those technologies and applications that are already well established, or are technologically available in the immediate future should policies wish to guide additional biomass in these directions. These are the applications most likely to place demands on Massachusetts' forest resources in the short term. Still, because of the amount of federal investment for research and development in some of the emerging technologies, which, if realized, have the potential to significantly affect demand for forest resources (such as cellulosic ethanol), a third category of applications is discussed in Section 2.5, entitled "Emerging Technologies." All of the liquid biofuels options for producing transportation fuels fall into this category, as does gasification and bio-char production.

Among these application areas, we selected 12 technology pathways to describe how biomass might be used, and compared them to their six fossil fuel equivalent applications. These are described in Appendix 2-A, and summarized in Appendix 2-B.

2.2 ELECTRICITY GENERATION

2.2.1 CURRENT SOURCES OF ELECTRICAL SUPPLY

Massachusetts uses about 55.8 million Megawatt hours (MWH) of electricity (Energy Information Administration—EIA, 2010) and produces about 47.1 million MWH (EIA, 2007). Massachusetts is a member of ISO New England, which is responsible for wheeling power throughout the region and bringing in power from other regions as needed. Of the power the state produces, renewables account for about two million MWH (4.3 percent), with biomass power generation accounting for 119,000 MWH, or six percent of the renewable portfolio and 0.3 percent of total production (EIA, 2007). Ten natural gas-fired power plants are now the state's leading power producers, accounting for over half of net generation. Coal, primarily from Colorado and West Virginia, is the state's second leading generation fuel; it is used in four plants and accounts for about 25 percent of net electricity production. Massachusetts also uses oil-fired systems (seven existing plants—although oil has been increasingly replaced by natural gas over the past decade) and nuclear from the Pilgrim plant to round out the remaining percentages of its profile. Of the renewables, landfill gas is the largest contributor, accounting for about 1.1 million MW followed by hydroelectric generation at 797,000 MWH (EIA, 2010).

The nuclear facility, all of the fossil fuel based power, and solid-fuel biomass power plants all use steam turbine technology, which has the common attribute of being approximately 25 to 32 percent efficient at converting the energy value of the fuel to electricity. Unused heat in these systems is released through cooling towers, or through heat exchanged in Cape Cod Bay in the case of the Pilgrim Nuclear facility (Entergy, 2008). The four coal facilities use 382,000 tons of coal each year (EIA, 2007), and the wood facilities[4], at full operation, would use approximately 215,000 green tons annually (INRS, 2007).

2.2.2 ELECTRICAL GENERATION PATHWAYS

Pathways 1–4 describe the range of power facilities used now, and for the foreseeable future, to produce electricity. Pathway #1 assumes a 50 MW biomass powered facility, and enables comparison to two fossil fuel options for coal (Pathway #3) and natural gas (Pathway #4) as well as a co-firing option where wood is substituted for 20 percent of the coal at a coal-fired unit (Pathway #2).

All pathways assume advanced pollution controls as needed to ensure the units are performing to meet expected pollution control objectives, but the efficiency is an average based on present performance of units in use today. Generally, this is 32 percent for coal, 20–25 percent for woody biomass, and 33 percent for natural gas (Appendix 2-B).

[4] There are two wood-fired electrical facilities in Massachusetts: Pinetree-Fitchburg (14 MW) which is operating and Ware Co-Gen (8.6 MW) which is idle (INRS at 40).

The following chart (Exhibit 2-1) presents the CO_2 emissions for the four electrical generation pathways.

Exhibit 2-1
Electrical Generation Pathway CO_2 Emissions

Electrical Generation Pathway	CO_2 Emissions (lbs/MMBtu)	CO_2 Emissions (lbs/MWH)
Coal (Pathway #3)	642	2,189
Modern Woody Biomass (Pathway #1)	863	2,945
Natural Gas (Pathway #4)	355	1,211
Co-firing with 20% wood* (Pathway #2)	684	2,334

*Total emissions for coal and wood combined.

These pathways are used to evaluate and compare different scenarios for forest management and carbon impacts if policies are directing biomass use toward stand-alone electrical generation, and to enable comparison to the most likely fossil fuel alternatives. Of all the fuels considered, natural gas is the cleanest and the lowest carbon emitting due to its ability to generate power using a direct combustion turbine at higher efficiency than traditional steam turbine technologies, and the fact that it has less carbon per unit of energy.

2.3 THERMAL PRODUCTION

Roughly one-third of the nation's energy demands are thermal demands for heat, hot water, cooling, and industrial process heat (EIA,2008),. In the Northeast, this percentage is even higher, with the region using 82 percent of the nation's home heating oil (EIA, 2009). In Massachusetts, 42 percent of the households and businesses use #2 heating oil or propane as their primary source of heat (EIA, 2007).

At the residential and community scale, biomass can be an effective means of using local wood resources and displacing fossil fuels efficiently. Generally, these thermal systems are between 75 percent and 85 percent efficient (See Appendix 2-B).

2.3.1 CURRENT SOURCES OF THERMAL SUPPLY

2.3.1.1 Residential Biomass Forms and Uses

Biomass has been used to heat homes for millennia. The amount of biomass used to heat Massachusetts' homes is not known, but is estimated at between one and two million green tons annually (Personal Communications, MADOER, 2010). Residential applications use biomass in fireplaces; wood stoves, furnaces, and boilers[5]; pellet stoves furnaces and boilers; and outdoor wood boilers. These applications decrease in efficiency (California Air Resources Board-CARB, 2005) and increase in emissions as one moves from pellet stoves and boilers to wood stoves and boilers to outdoor wood boilers to fireplaces.

Exhibit 2-2 presents efficiency, particulate, and CO2 emissions associated with these residential applications.

Exhibit 2-2
Residential Wood Appliance Efficiencies and Emissions

Wood Appliance	Efficiency	Particulate Emissions	CO_2 Emissions (lbs/MMBtu)
Masonry Fireplace	-10% to 10%	50 g/hr	2,157.0
Outdoor Wood Boilers	28% to 55%	55 g/hr to 143 g/hr (Pre-2007) 15 g/hr (Post-2007, Voluntary)	359.5
Fireplace Insert	35% to 50%	.94 to 3.9 g/kg	507.5
Airtight Stove	40% to 50%	10-20 g/hr (estimate based on Cert .3 of old wood stoves)	479.3
EPA-Certified Stoves and Inserts	60% to 80%	2.5 to 7.5 g/hr (EPA, 2/22/10)	317.2
Residential Pellet Stoves	75% to 90%	<1 to 2 g/hr (EPA, 2/22/10)	269.6
Residential Pellet Boilers	80% to 90%	<1 to 2 g/hr (EPA, 2/22/10)	239.7

2.3.1.2 Institutional Biomass Forms and Uses

Use of biomass for heat and hot water in community buildings, institutions, etc. has had limited application in Massachusetts. Two examples are: Quabbin Reservoir Administrative Building in Belchertown, and Mount Wachusett Community College in Gardner. The Quabbin system was installed in 2008 and uses 350 tons of wood per year to displace 22,000 gallons of #2 heating oil (Biomass Energy Resource Center-BERC, 2010). It is 2.0 MMBtu/hr in size. The Mount Wachusett system is 8.0 MMBtu/hr in size, was installed in 2002 and uses between 1,200 and 1,400 tons of wood each year (BERC, 2010). This system replaced electric heating, and the college estimates it has saved 30 million kWh of electricity in the eight years of operation (BERC, 2010). The technology for these systems uses centralized hot water-based boilers and underground insulated pipe distribution systems.

Other applications of this scale of system are used in several schools. Several colleges are considering conversion to biomass, including UMASS Amherst, and the VA hospital in Northampton.

2.3.2 THERMAL PRODUCTION PATHWAYS

Pathways 5–10 describe the range of applications that may be used for thermal production, beginning with cordwood systems that would serve a typical home (Pathways #5 and #6). These boilers represent small systems that, at 100,000 Btu/hr, would be used to serve a small business or residence. The difference between these two pathways is that Pathway #6 represents an EPA-certified boiler that is more efficient and therefore has fewer carbon emissions per energy output than Pathway #5.

Pathway #7 describes a pellet system, separated into two parts in order to compare effectively with other sources of thermal energy presented—pellet manufacturing is Pathway 7A and covers the process of using green wood chips to produce pellets, and Pathway 7B describes the use of these pellets in a typical commercial or institutional setting, sized at 5.0 MMBtu/hr. When considering pellets and comparing to other fuels with respect to harvesting needs and carbon impacts, it is important to consider both pathways.

[5] A stove is considered to be a stand-alone space-heating device, a furnace is a central hot air system, and a boiler is a central hydronic (hot water pipe and radiator) system.

Pathway #8 is a wood chip system sized at 50 MMBtu/hr, which would serve a community in a district energy system of the kind commonly used in Europe. Pathways #9 and #10 provide information about the fossil fuel equivalent versions of this system, using #6 heating oil and natural gas, respectively.

Exhibit 2-3 presents the CO_2 emissions from these thermal pathways[6]:

Exhibit 2-3
Thermal Generation Pathway CO_2 Emissions

Thermal Generation Pathway	CO_2 Emissions (lbs/MMBtu)
Wood chip-fired District Energy (Pathway #8)	288
Non EPA-Certified Residential Wood Boiler (Pathway #5)	360
#6 Heating Oil (Pathway #9)	217
Natural Gas (Pathway #10)	138

2.4 COMBINED HEAT AND POWER OPTIONS

All electrical production from combustion of fuels creates excess heat that is often wasted. In the case of power plants, excess heat is often released through cooling towers, as steam from the turbine is condensed and returns to the boiler. Combined heat and power systems (CHP) seek to utilize some or all of this excess heat. As this excess heat is made into useful energy, the efficiency of the generating system increases with the proportion of heat it uses. Generally, using conventional technology, for each unit of electricity produced, three units of thermal energy are released.

Electricity-led CHP is an option where power production is near a thermal demand. A 20 MW power plant produces enough heat to heat approximately 1,100 homes[7]. However, to date, the economics, incentives and siting preferences have not resulted in power plants choosing this route. As a result, regardless of the fuel source producing the electricity, approximately 75 percent of the energy value of the fuel has been wasted as lost heat. Taking advantage of this energy value requires planning, intentional siting, and either financial or regulatory incentives that promote power producers deciding to increase the complexity of their systems by the addition of steam or hot water as a salable output. This is not the business model that has been pursued to date. Recently, with the increased understanding of efficiency and concern about efficient use of resources, biomass power facilities are beginning to incorporate some CHP in their proposals, though because of the large amount of heat available relative to potential nearby uses, these projects often make use of only a small percentage of the available heat (10–15 percent).

[6] As with the other exhibits which follow, the source of data for these charts is presented in Appendix 2-B

[7] 20 MW electric produces approximately 136 MMBtu/hr of heat. Residential heating typically uses 40 Btu's/sq ft. Based on a 3,000 square foot house, heating requirement is 120,000 Btu's/hr, or 1,137 homes.

Thermally led CHP maximizes the demand for heat, but produces relatively little electricity. At the community scale, a typical CHP facility might produce 1–5 MW of electricity while heating a college campus or small community district of 200–500 homes and businesses.

An important point to note is that the efficient scale of producing electricity alone leads to plants in the 20–50 MW size range. At this scale, it is more cost-effective to produce the power, and any CHP component is a complicating factor that tends to reduce the overall cost-effectiveness of the project under current policies. At smaller scale thermal-led CHP systems, the opposite is true—production of heat alone maximizes cost-effectiveness of the project, and adding an electrical component reduced the overall economics of the project, i.e. the savings in heat help subsidize the electrical generation components.

Conventional technology requires the production of steam to produce electricity, but European commercial technologies include gasification where the produced gas is combusted directly in a combustion turbine, or Organic Rankine Cycle (ORC) thermal oil technology which uses a thermal oil to gain temperature gradients necessary to produce electricity without steam, so that the thermal system can be designed around hot water, and at low pressure. The ORC system, while more easily incorporated into a hot-water based thermal application and therefore of greater potential in smaller CHP systems (see below), the ORC process is still only approximately 20% efficient on its own in the production of electricity, but would be expected to be between 75% and 85% efficient in heat-led applications. Heat-led gasification can be expected to be approximately 75% efficient. (See Appendix 2-B for sources of efficiency information).

2.4.1 CHP PATHWAYS

Pathways #11 and #12 describe moderate-sized CHP systems capable of producing 5.0 MW of electricity. The first uses conventional technology, producing steam to run a turbine, and fully utilizes the 34 MMBtu/hr of heat generated to heat facilities on the order of magnitude of a college campus, a hospital, or small community. As such, the overall efficiency is rated at 75 percent. The second pathway uses gasification technology, which is just an emerging technology here in the United States. Still, there is an example of a commercial system operating since 2000 in the Town of Harboøre, Jutland, Denmark that produces 1.6 MW of electricity and heats 900 homes (BERC, 2010). The efficiency rating for this system is also 75 percent.

Pathways #13 and #14 are the fossil fueled equivalent of the biomass CHP systems for oil and natural gas.

Exhibit 2-4 below presents CO_2 emissions for the four CHP pathways considered.

Exhibit 2-4
CHP Generation Pathway CO_2 Emissions

CHP Generation Pathway	CO_2 Emissions (lbs/MMBtu)
Wood chip Steam System (Pathway #13)	287
Wood chip Gasifier (Pathway #14)	287
Oil System (Pathway #15)	232
Natural Gas System (Pathway #16)	146

2.5 EMERGING TECHNOLOGIES

There are several emerging technologies for using biomass that have the potential to change the demand for low-grade wood over time. Most of these are transportation sector related. The US Department of Energy has invested hundreds of millions of dollars over the last decade to augment the ethanol production of agricultural crops (corn primarily) with ethanol derived from woody-biomass sources (cellulosic ethanol). To date, they have sponsored both research and development, funding six pilot scale plants throughout the country. While not yet commercially viable, our transportation fuel demands are so high and this is another area, like heating oil, directly related to our importation of fossil fuels, that the issue is an important one to consider in the context of making policies to support the sustainable use of the low-grade wood resource. To put it in context, the Range Fuels plant near Soperton, Georgia will begin at pilot scale producing 20 million gallons of cellulosic ethanol a year, using 250,000 tons of wood. At its commercial scale of 100 million gallons per year, the wood demand will be over 1.2 million tons of green wood per year for this one plant (Range Fuels, 2010).

Smaller scale work in bio-oil (pyrolysis oil) and bio-char (torrefaction) are emerging technologies that can help with both transportation fuel alternatives to gasoline and diesel, as well as, in the case of bio-char, potentially sequester portions of the wood carbon for long periods of time (Laird, 2008). These systems are operational at very small scales at the moment, but have a potential to contribute positively to the biofuel equation.

There are other technologies of similar scale to the bio-oil that use biomass to produce a range of products, including fertilizers, plastics, and glues. All of these products are relatively limited in demand, so source material from forests will not be significant relative to energy demands or other forest product uses.

2.5.1 EMERGING TECHNOLOGY PATHWAYS

The emerging technologies represented here all use some of the heat for other aspects of their processes, so their efficiencies are generally in the 40–45 percent range. Pathway #15 provides an example of a commercial-scale cellulosic ethanol plant, making 100 million gallons of cellulosic ethanol per year. In this process, the cellulose in the wood is converted to sugars that are fermented into alcohol. The lignin part of the wood is combusted directly to produce steam and electricity. Pathway #18 is a variation on this whereby the by-product of pyrolysis is used to produce other products, such as plastics, glues, organic fertilizers, and fuel additives instead of electricity. Pathway #16 represents a bio-oil and bio-char system, producing 15 million gallons/year of bio-oil, and approximately 21,575 tons of bio-char (charcoal), having heating value of 11,000 btu/lb (dry basis), that can be used as a soil amendment for carbon storage. Pathway #17 is of similar size, producing a syngas that is used to make liquid fuels, with lignin used to produce steam-based electricity. The following chart summarizes the CO_2 implications of these pathways:

Exhibit 2-5
Emerging Technology Pathway CO_2 Emissions

Emerging Technologies Pathway	CO_2 Emissions (lbs/MMBtu)
Cellulosic Ethanol (Pathways #15 and #18)	255
Bio-products Pathway (Pathways #16 and 17)	119

2.6 GENERAL DISCUSSION AND SUMMARY

2.6.1 THE FUTURE ROLE OF BIOMASS UNDER PRESENT POLICIES

Electricity demand is expected to increase by approximately 1.2 percent annually, with a peak demand increase of 1.3 percent due to increased cooling demand in the summer (ISO New England Inc., 2009). Air pollution goals, as well as cost and projected supplies, will continue to drive new power production toward natural gas, but for the state's RPS. In an attempt to reach 15 percent by 2020, Massachusetts is looking to alternatives to fossil fuels to reach its goals. There are several significant wind projects in place and in planning, as well as solar projects, but as biomass power is "base load," the trend has been to look to it to supply an increased share of the electricity portfolio.

Over the next five to 10 years, barring a change in policy or incentives, or a dramatic change in the price of fossil fuel or electricity, we would expect the current pattern of incremental proposal and construction of stand-alone biomass power plants between 20 MW and 50 MW to continue to be the major focus of the use of biomass. As described elsewhere, the pattern has been for many to be proposed (214 throughout New England over the past decade, with one constructed), and there are currently four proposals in Massachusetts. In part, the low ratio of "proposed" to "constructed" reflects the marginal economics of constructing plants based on the present cost of electricity, and the desire for investors to recoup costs of capital investment within a relatively short period of time—most private investors look for a return on investment of 20 percent within two to five years[8].

Events that can speed this up are if the wholesale rates of electricity increase substantially while the policy direction for renewables is maintained. In 2008, Massachusetts paid an average of 16.27 cents/kWh retail for electricity, the fourth highest in the nation and highest in New England. It is doubtful that electricity prices will increase dramatically in the face of the downward regional and nationwide pressure on prices. If Renewable Electricity Credits (REC's) rise in value and are stabile over a period of several years, this too would encourage construction of more power plants.

8 It also reflects the tendency for proposers to announce projects at a very early stage of project development as a relatively easy means of assessing public acceptance of a given project, so the public announcements are not a good gauge of projects that are truly in advanced development and are likely to be built.

Factors that can make power plant investment slow down are low value of REC's coupled with only an inflationary increase in the price of electricity. Also, if the availability of fuel supply is restricted, or if it is only available at a cost higher than what plants can afford to pay, biomass power will be discouraged. We consider this scenario to be possible, but unlikely in the immediate future.

While incentives and policies may promote biomass electric plant construction, the pace and penetration of biomass power plants are controlled most significantly by the fuel supply; it is such a large portion of the cost of operations that it is looked at very carefully by investors. This is why multiple proposals may be vetted at a given time, but if one is built, the others in the wood-basket are significantly adversely affected and are less likely to go forward. If there are reasonable harvesting and procurement standards in place regarding overall sustainability, this factor is likely to increase the due diligence on available fuel supply and prevent over-development of biomass power facilities.

If policies are changed to require CHP or a minimum annual net efficiency standard, as some states have done in certain circumstances and as DOE encouraged in recent procurements, more CHP can be expected. But under current conditions, siting constraints, the required scale for economically viable power production and lack of large centralized demand for thermal at the scale produced by a 20–50 MW power plant will all limit the desirability of power developers to include heat, as well as the amount of heat that can be effectively used by an electricity-led CHP system. We do not see electricity-led CHP as growing in the absence of policies or incentives to encourage that direction.

Residential conversions are very dependent on oil and propane prices. In the absence of policies that would encourage large-scale switchover to biomass in residences, such as a substantial increase in the residential tax credit, or a change in building codes or insurance standards (to not require a conventional fossil fuel-based system in the home), the trend is expected to remain about the same. Although the use of biomass for home heating is significant, and currently not well-quantified, dramatic changes in the trend are not expected, though as explained below, residences can react quickly to rapid oil and propane price increases.

At this scale, residential use will not be a significant driver in determining Massachusetts' forest resource capacity for increased biomass use or the overall sustainability of the resource. Accordingly, the analyses in subsequent sections of this report assume residential use (and all existing uses for that matter) remains about the same as they are. That said, things which weigh in on people's decisions to burn wood in the home primarily relate to cost of the fossil fuel alternative, and while this consideration may be at the forefront individual preferences regarding energy security and price stability, ease of operation and maintenance, degree of automation and convenience, cleanliness, availability of the wood fuel, heating effectiveness and comfort all play a role. Other factors such as emissions, environmental benefit, energy independence, space, and cumulative impacts are of lesser importance to the individual decision.

Biomass options in the home most closely able to substitute for oil are pellet boiler and furnace systems, and these systems are very popular in Europe and increasingly so here. The obstacles preventing large conversion of homes are primarily related to price. A conventional central heating system costs between $2,500 and $4,000 for a typical home. A comparable pellet system would be between $5,000 and $8,500. Even though the fuel is cheaper than oil, its availability in bulk is presently limited, and the cost disparity in systems cannot be made up for by the present 30 percent tax credit that has a cap of $1,500 per home.

If one wishes to promote advanced biomass technologies for the home, incentives such as tax credits, change-out programs, and programs that allow homeowners to offset the additional costs of choosing a biomass system either through credits or ability to finance costs through low or no cost options all work to overcome the cost implications. Proposals are pending in Congress to raise or eliminate the tax credit cap, and to develop a Homestar program that among other things supports pellet system installations. Similarly, New Hampshire and Maine each have programs to encourage an expanded residential market. A reliable bulk delivery option and convenient storage and automated delivery to the boiler or furnace are also necessary for the residential use of pellets to increase significantly and displace oil and propane.

Cordwood use is limited in growth to those capable of handling and tolerating the storage, handling, and messiness of cordwood. Outdoor wood boilers avoid some of the indoor mess of handling cordwood, but the low efficiency and high emissions from them are of increasing concern to states in the Northeast, even when compared to conventional wood stoves. Though they are improving, some of the cost-attractiveness of these systems will be lost as their technology improves.

One hears periodically about home-based CHP systems, but with regard to biomass systems these are not commercially available, and developing products are very expensive relative to either conventional fossil fuel or biomass thermal systems. There are some demonstration projects using a Stirling Engine design, but these are still experimental or unique applications (Obernberger, et. al, 2003). We conclude from this that electrical generation from wood at the residential scale is not commercially available.

With respect to residential heating, it is important to recognize the individual residential component and fuel price sensitivity of the cordwood market when considering net available low-grade wood for sustainable biomass use. Although each homeowner's use is relatively small—perhaps five to 10 tons per season (2-5 cords)—cumulatively, it can be significant, and often the hardest sector to quantify. In Vermont for example, cordwood is estimated to account for between 30 and 40 percent of all biomass use in the state (BERC, 2007). It increased by 20–30 percent in the single season of 2008 when oil approached $150/barrel.

There will also likely be small, incremental increase in thermal applications of biomass at colleges, institutions, and other facilities that have the capital to invest in longer-term payback projects, as the economics are compelling at current or slightly higher than current heating oil prices. These are not going to be common or numerous, as few institutions have the capital to make the change-over, and the payback period of generally between seven and 12 years is too long for private investment interest. To increase thermal applications dramatically, if that is a policy direction Massachusetts wishes to pursue, state and federal incentive programs to provide capital, such as through a revolving loan fund, would be needed .

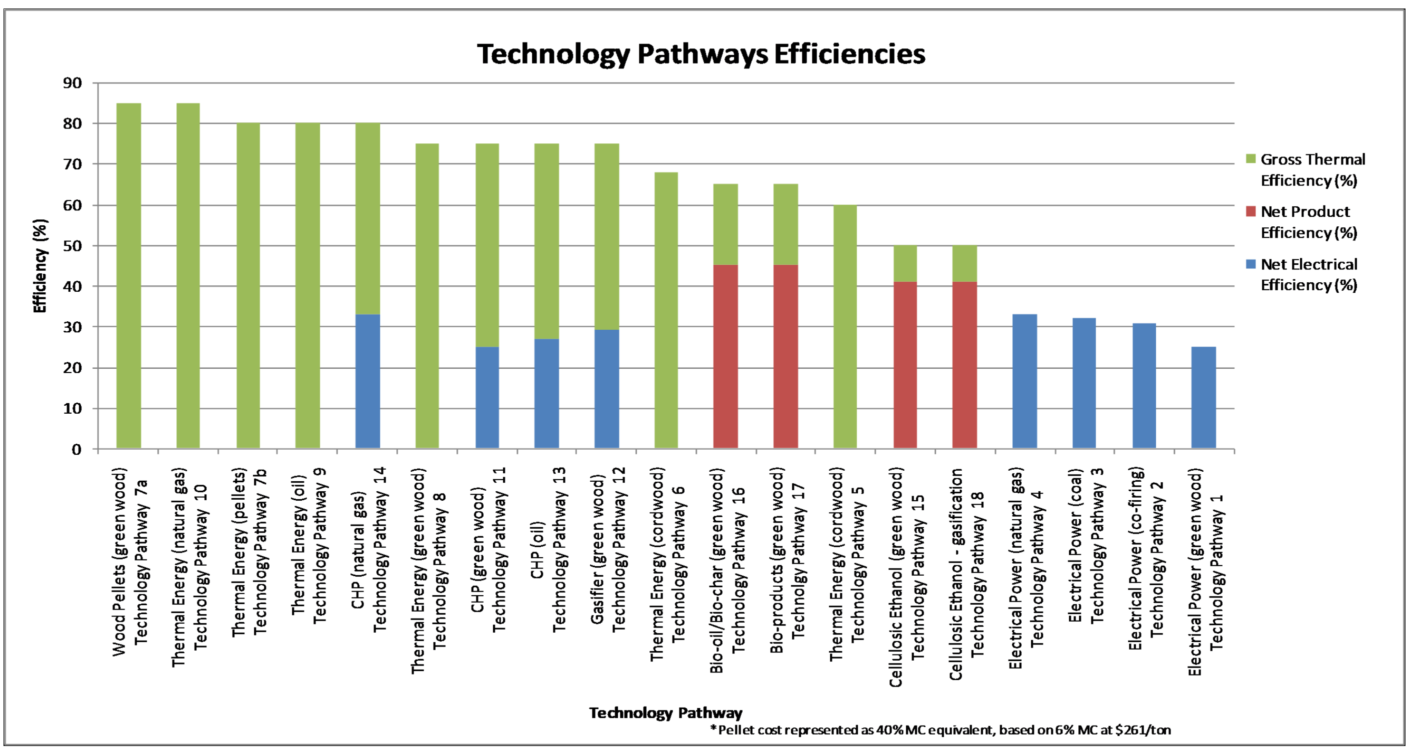
Finally, cellulosic ethanol production has the potential to completely usurp power production at a comparable scale if electricity prices remain low, and oil (gasoline) prices increase markedly. However, the pilot projects under way and supported by the US DOE must prove out, and as such, we consider this scenario to be worthy of watching, but unlikely—especially in the near five to 10 year timeframe.

2.6.2 EFFICIENCY

As has been discussed throughout, converting biomass into different energy pathways and products yields varying ranges of efficiency for extracting the energy value of that biomass resource. Exhibits 2-6 and 2-7 on the following pages show the range of efficiencies for the different applications and pathways selected from most efficient to least efficient.

It is important to recognize that what is presented is just the efficiency of the process to produce energy or fuel or product from the biomass. This does not include up-front processes to get the biomass to the facility, or additional losses incurred through the use of the end product. For example, for electricity, these efficiencies do not include line losses or the efficiency of a given appliance to turn remaining electricity into useful work. Similarly, for the transportation fuels, this does not include the relative inefficient (18 percent) ability of your car to take the energy value of the fuel and convert it into the work of moving you down the road. Finally, for the thermal applications, it does not include the loss of heat exchange from the thermal system to a home, or the efficiency of a home to retain heat. These examples show that further down the process more losses of the energy value of the original biomass will be incurred. They may be smaller or they may be quite large, depending on the end use.

Exhibit 2-6: Graph of Efficiency of 18 Technology Pathway Options[9]



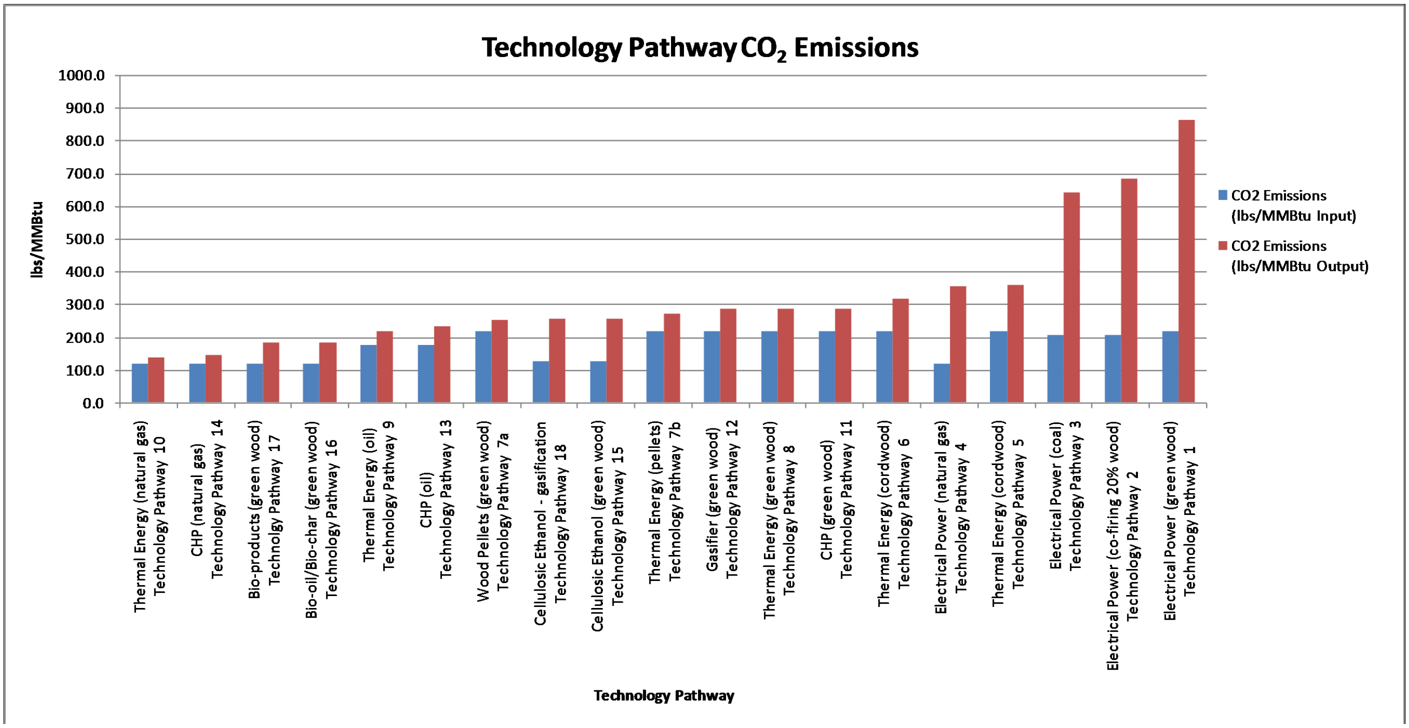
[9] Graph information is derived from Appendix 2-B. See that Appendix for data and sources.

Exhibit 2-7: Chart of Efficiency of 18 Technology Pathway Options[10]

Technology Pathway	Net Electrical Efficiency (%)	Net Product Efficiency (%)	Gross Thermal Efficiency (%)
Wood Pellets (green wood) Technology Pathway 7a			85
Thermal Energy (natural gas) Technology Pathway 10			85
Thermal Energy (pellets) Technology Pathway 7b			80
Thermal Energy (oil) Technology Pathway 9			80
CHP (natural gas) Technology Pathway 14	33		47
Thermal Energy (green wood) Technology Pathway 8			75
CHP (green wood) Technology Pathway 11	25		50
CHP (oil) Technology Pathway 13	27		48
Gasifier (green wood) Technology Pathway 12	29		46
Thermal Energy (cordwood) Technology Pathway 6			68
Bio-oil/Bio-char (green wood) Technology Pathway 16		45	20
Bio-products (green wood) Technolgy Pathway 17		45	20
Thermal Energy (cordwood) Technology Pathway 5			60
Cellulosic Ethanol (green wood) Technology Pathway 15		41	9
Cellulosic Ethanol - gasification Technology Pathway 18		41	9
Electrical Power (natural gas) Technology Pathway 4	33		
Electrical Power (coal) Technology Pathway 3	32		
Electrical Power (co-firing) Technology Pathway 2	30.6		
Electrical Power (green wood) Technology Pathway 1	25		

10 Chart information is derived from Appendix 2-B. See that Appendix for sources.

Exhibit 2-8: Graph of CO_2 Emissions of 18 Technology Pathways[11]



2.6.3 CARBON IMPACTS

The CO_2 emissions from each of the pathways vary depending on the fuel and the efficiency of the product made. Generally, the CO_2 emissions expressed as "input" energy reflect the fuel the process is based on, and the CO_2 emissions based on "output" energy reflect the efficiency of the biomass-product conversion, be that electricity, thermal, or fuel. Exhibits 2-8 and 2-9 on the following pages reflect the different pathways from least CO_2 emissions based on energy output to the most emitting pathways.

As with the efficiency discussion, it is very important to note this is not a life-cycle analysis of these technology pathways. The carbon aspects of mining coal, harvesting biomass, or drilling and transporting natural gas or oil are not shown here. Nor, except for the electricity and thermal applications, are the emissions of the ultimate use accounted for—that is, the fuels combusted will further release CO_2 associated with that product. While full carbon life-cycle accounting for all pathways is beyond the scope of this work, lifecycle estimates of carbon emissions for the technological options considered in Chapter 6 are provided there.

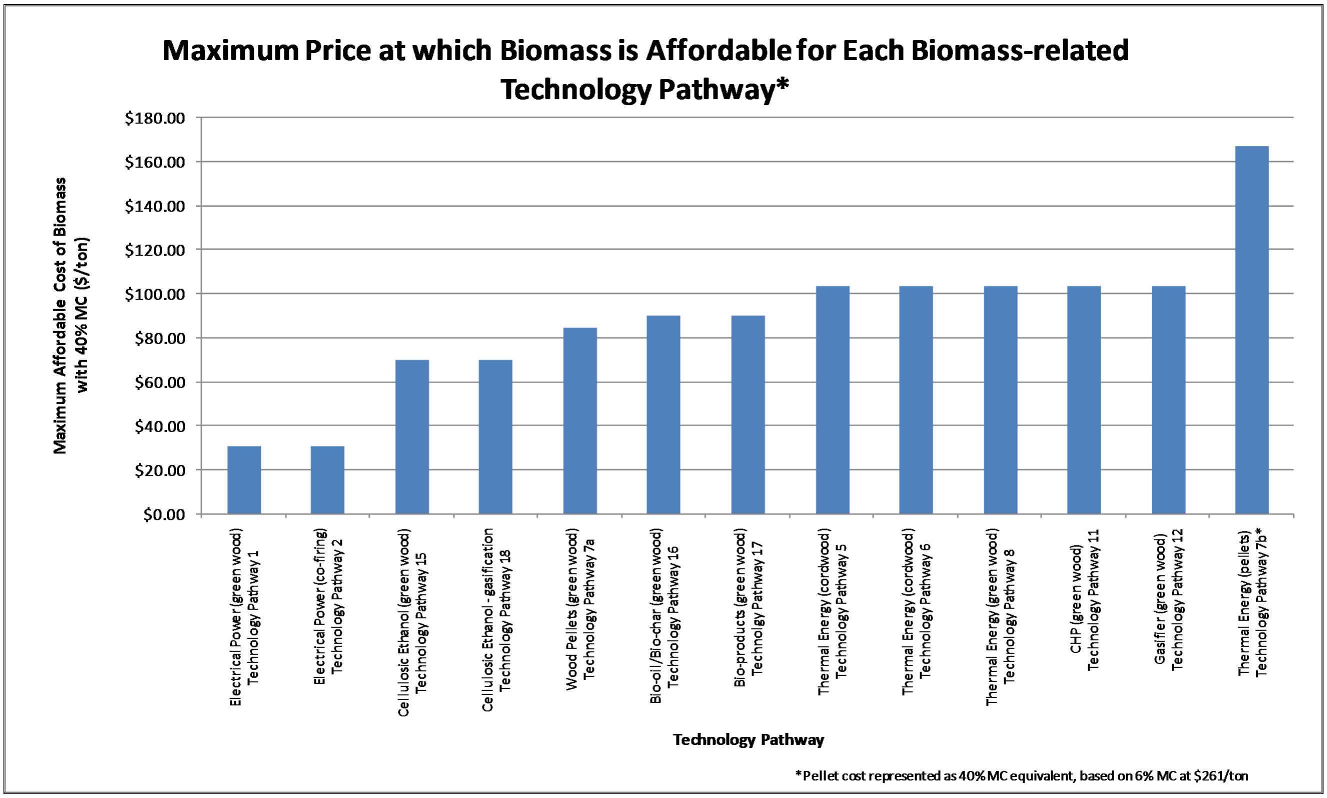
11 Graph information is derived from Appendix 2-B. See that Appendix for data and sources.

12 Chart information is derived from Appendix 2-B. See that Appendix for sources.

Exhibit 2-9: Chart of CO_2 Emissions of 18 Technology Pathways[12]

Technology Pathway	CO_2 Emissions (lbs/MMBtu Input)	CO_2 Emissions (lbs/MMBtu Output)
Thermal Energy (natural gas) Technology Pathway 10	117.0	137.6
CHP (natural gas) Technology Pathway 14	117.0	146.3
Bio-products (green wood) Technolgy Pathway 17	118.6	182.5
Bio-oil/Bio-char (green wood) Technology Pathway 16	118.6	182.5
Thermal Energy (oil) Technology Pathway 9	173.9	217.4
CHP (oil) Technology Pathway 13	173.9	231.9
Wood Pellets (green wood) Technology Pathway 7a	215.7	253.7
Cellulosic Ethanol - gasification Technology Pathway 18	127.3	254.5
Cellulosic Ethanol (green wood) Technology Pathway 15	127.3	254.5
Thermal Energy (pellets) Technology Pathway 7b	215.7	269.6
Gasifier (green wood) Technology Pathway 12	215.7	287.6
Thermal Energy (green wood) Technology Pathway 8	215.7	287.6
CHP (green wood) Technology Pathway 11	215.7	287.6
Thermal Energy (cordwood) Technology Pathway 6	215.7	317.2
Electrical Power (natural gas) Technology Pathway 4	117.0	354.5
Thermal Energy (cordwood) Technology Pathway 5	215.7	359.5
Electrical Power (coal) Technology Pathway 3	205.3	641.6
Electrical Power (co-firing 20% wood) Technology Pathway 2	207.4	684.3
Electrical Power (green wood) Technology Pathway 1	215.7	862.7

Exhibit 2-10: (below) Maximum Price at which Biomass is Affordable for Each Biomass-Related Technology Pathway[13]



2.6.4 AFFORDABLE COST FOR BIOMASS SOURCE MATERIAL

Finally, for the purposes of conducting sensitivity analyses of the demand for forest products and how demand might affect cost paid for biomass, and how, in turn, that affects harvesting methods, intensity and options, we have looked at what the maximum affordable price is for each pathway to pay for biomass from the forests. The following Exhibits 2-10 and 2-11 illustrate these prices.

The maximum affordable price for power generation has been calculated based on the wholesale price of 12.5 cents per kWh including REC benefits, the cost of biomass fuel as 33 percent of sale price, higher heating value of wood chips as 17 MMBtu/ton, and moisture content of wood chips as 40 percent. The maximum affordable price for thermal applications has been calculated based on the price of #2 oil as $3 per gallon, higher heating value of 138,000 Btu/gallon, combustion efficiency of 80 percent for oil boiler, affordable price of wood chips as percent of price of oil on $/MMBtu basis as 50 percent and the combustion efficiency of wood chips boiler as 75 percent. The maximum affordable price of wood pellets for thermal energy has been calculated based on e f wood pellets with six percent moisture content as percent of price of oil on $/MMBtu basis as 75 percent and the combustion efficiency of wood pellet boiler at 80 percent. The maximum affordable price of wood chips for manufacturing wood pellets have been calculated based on maximum affordable price of wood pellets for thermal energy at $261 per ton, efficiency of conversion of wood chips to wood pellets as 85 percent, requirements of wood chips per ton of wood pellets as 1.575 tons, and the affordable price of wood chips as 60 percent of the price of wood pellets. The maximum affordable price for other technology pathways has been estimated in proportion of the net efficiencies for the products.

The maximum affordable price is important as the price one is willing and able to pay for biomass determines the type of equipment and treatments that can be applied to the forest, and which uses may get preference over others with respect to biomass product. Higher affordable prices may enable better management, landowner commitment to sustainable forestry, and enhancement of logging infrastructure and methods. The pathways constraining the electricity related biomass prices are based on an electricity wholesale price of 12.5 cents/ kWh, which assumes a wholesale price to the grid plus any value of REC's. Thermal applications are based on a $3.00 per gallon oil equivalent. Obviously, if the price of either goes up, then the ability to pay more for biomass (and still have the project "break even") goes up as well. All of the assumptions for this and the other analyses are shown in the attached Appendix 2-C.

13 Graph information is derived from Appendix 2-B. See that appendix for data and sources. Methodology for calculations is presented in Section 2.6.4.

Exhibit 2-11: Maximum Price at which Biomass is Affordable for Each Biomass-Related Technology Pathway[14]

Technology Pathway	Maximum Affordable Cost of Biomass with 40% MC ($/ton)
Electrical Power (green wood) Technology Pathway 1	$31.00
Electrical Power (co-firing) Technology Pathway 2	$31.00
Cellulosic Ethanol (green wood) Technology Pathway 15	$70.00
Cellulosic Ethanol - gasification Technology Pathway 18	$70.00
Wood Pellets (green wood) Technology Pathway 7a	$85.00
Bio-oil/Bio-char (green wood) Technology Pathway 16	$90.00
Bio-products (green wood) Technolgy Pathway 17	$90.00
Thermal Energy (cordwood) Technology Pathway 5	$104.00
Thermal Energy (cordwood) Technology Pathway 6	$104.00
Thermal Energy (green wood) Technology Pathway 8	$104.00
CHP (green wood) Technology Pathway 11	$104.00
Gasifier (green wood) Technology Pathway 12	$104.00
Thermal Energy (pellets) Technology Pathway 7b*	$167.00

[14] Chart information is derived from Appendix 2-B. See that appendix for sources.

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