# Biomass Energy Crops: Massachusetts' Potential

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**Executive Summary**

In Massachusetts, biomass energy has typically meant wood chips derived from the region's extensive forest cover. Yet nationally, biomass energy from dedicated energy crops and from crop residues is thought to have significantly more potential than forest biomass energy (Perlack, Wright et al. 2005). One key feature of biomass energy crops is that they can have much higher energy yields per hectare than are available from the forest. Thus a relatively small amount of agricultural land might be used to produce a disproportionate amount of the Commonwealth's biomass energy.

In this study we focus on perennial crops that can be used in solid-fuel applications, specifically willow as a short-rotation woody crop, and switchgrass as a perennial grass crop. In both cases the crops can clearly be grown in Massachusetts, though it is less clear how much such energy might be delivered at what price. Based on studies in other areas, it appears that prices for both willow and switchgrass would be higher than current prices of forest wood chips, though perhaps equal to plausible future forest wood chip prices. It also appears that switchgrass may be more expensive per unit of energy than willow, though switchgrass can more easily produce a dry fuel. Switchgrass in the form of dry pellets may be better adapted to meeting small commercial and residential heating needs, while green and less expensive willow chips may be more important as an institutional heating or power plant fuel.

We examine potential biomass energy demand in the 5-county area, and then review crop production potential in three scenarios: 1) switching of crops on existing farmland, 2) use of farmland that is no longer part of active farms, for which we use GIS and Census of Agriculture data to estimate an upper bound on such land availability, and 3) the possibility of returning some land that is currently forested to farmland, based on historical data on farmland cover in Massachusetts. Converting land currently in forest clearly holds the largest potential production, though little is known about actual biomass crop yields or production costs on these lands, ecological consequences of such land conversion, or public and landowner attitudes about land cover changes.

We also review critical needs for future research on biomass energy crops, of which there are several.

## Table of Contents



## Tables and Figures

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## Purpose and Scope

This assessment of biomass energy crop potential is one project of the Massachusetts Sustainable Forest Bioenergy Initiative. The Initiative is a multifaceted study of biomass energy potential in Massachusetts, assessing the possible extent and impacts of expanding bioenergy use, as well as assessing possible obstacles. Activities of the initiative include, among other things, researching potential biomass supply and processing methods, researching sustainable biomass harvest levels and impacts on forest health, developing a strategic plan for establishing biomass supply infrastructure, and outreach to foresters and loggers. The Initiative is managed by the Massachusetts Division of Energy Resources with the Department of Conservation and Recreation and is funded by grants of $495,000 from the U.S. Department of Energy and $245,000 from the Massachusetts Technology Collaborative, Renewable Energy Trust.

Compared to wood-chip-derived biomass, the biomass energy crop industry is in its infancy in Massachusetts. Though perennial biomass crops including switchgrass and willow have been the subject of much discussion and study, there are few working examples of their production and use in the northeast. By contrast, wood-chip biomass already has significant working markets in New England. Thus this report on biomass energy crops is unavoidably somewhat conjectural. The main goals of the project are to suggest likely crops, costs, applications, and scope of a future biomass-crop sector in western Massachusetts, as well as to identify research needs. The study area includes the five westernmost counties of Massachusetts: Berkshire, Franklin, Hampden, Hampshire, and Worcester.

## Why Biomass Crops?

Dedicated biomass energy crops loom large in any national-scale plan to increase use of renewable energy and decrease carbon emissions associated with fossil fuel use. In the USDA's "Billion Ton Annual Supply" biomass report (Perlack, Wright et al. 2005), 73% of the identified biomass supply comes from agricultural sources, including both dedicated energy crops and residues from other crops. Of the agricultural sources, perennial crops are the largest projected source (38%), followed by corn stover (26%) and a number of smaller sources. Given that much of the nation's land mass is in agricultural use, it is perhaps not surprising that a national biomass strategy would rely heavily on agricultural biomass.

With forest dominating the Massachusetts landscape, one would expect that forest wood chips would be a more available resource than agricultural biomass, as indeed they are presently. Yet agricultural biomass has several attractions, chief among them the potential for greatly increased yields per hectare over forest biomass, and thus for potentially significant increases in the total Massachusetts biomass supply. Table 1 shows calculated energy production per hectare for forest biomass (from the Initiative's regional economic impact analysis), and possible yields from two perennial biomass crop sources.

**Table 1, Potential yields from different biomass sources**

| fuel | MA forest wood chips, net of saw logs | coppiced willow chips | switchgrass |
|---|---|---|---|
| tons/acre | 1.1[1] | 4.7[1] | 4.0[3] |
| moisture | 45% | 45% | 12% |
| MMBtu/ton | 9.3 | 8.8 | 13.8 |
| MMBtu/acre | 10.0 | 40.8 | 54.8 |

1. (Innovative Natural Resource Solutions 2007)
2. (Tharakan, Volk et al. 2005)
3. (Duffy and Nanhoue 2002)

Agricultural biomass appears to have yield potentials in the range of 4-5 times the energy per hectare as forest biomass, and these are some of the more conservative biomass crop yield figures in the literature. But note that forest biomass production is an average of all acreage actually forested in Massachusetts, which includes many areas of low productivity. A key research question is what level of perennial crop yield might be achieved on Massachusetts' more marginally productive lands. Biomass crops will almost certainly have higher production per hectare than forest crops, given that 1) biomass crops are selected specifically for their fast growth potential, unlike naturally occurring forest growth, and 2) in biomass crop production, virtually the entire above-ground portion of the plant is harvested for fuel, where in forest harvest a quantity of biomass is used directly for saw timber (about 30% of growth), and some debris is inevitably left behind in small-diameter tops, stumps, unharvested plants, etc. Thus while perennial energy crops would likely yield more biomass than forest on any given piece of land, the difference is likely less extreme than figures in Table 1 suggest.

Another potential advantage of biomass energy crops is preserving existing farmland and open space that might not be economically used to produce food crops, thus retaining traditional agricultural landscapes. Switchgrass in particular is similar in appearance to a traditional hay crop (though this is not true of short rotation woody crops). Increased production and use of biomass energy crops may also help to preserve and increase agricultural employment, rural infrastructure and services, etc.

A key question is at what cost biomass from energy crops might be produced. Most of the evidence from the literature (reviewed in more detail below) suggests that biomass crop prices per MMBtu will be significantly higher than current prices for forest biomass. Thus crop production costs may have to be significantly lowered, or demand for biomass energy significantly increased, before any such fuels enter the market. There are also multiple market potentials for biomass energy; while the Massachusetts Sustainable Forest Bioenergy Initiative focuses mainly on fuel for electricity generation, biomass from perennial crops might be more appropriately used, and be more competitively priced, as solid fuel for residential and commercial heating applications, as described below. Feedstock for cellulosic ethanol production is another emerging market, and oilseeds like cranbe for biodiesel production can also be grown in the Commonwealth.

Virtually any agricultural crop, crop residue, or animal waste can be used for energy in some way: through direct combustion, or after biological or chemical conversion to a liquid or gaseous fuel (e.g. ethanol or methane). In this study we focus on perennial crops intended primarily for direct combustion. Currently there are two main streams of research into such crops: 1) short-rotation woody crops as exemplified by willow, and 2) perennial grasses, of which switchgrass is the best-known example. The two crops types require somewhat different culture, yield different products, and have different economics, and thus are discussed separately below. As perennial crops, both crop types have advantages in soil conservation and soil carbon sequestration over annually tilled crops like corn or canola (Volk, Verwijst et al. 2004).

## Short-Rotation Woody Crop: Willow

Cultivating trees for fuel and fiber through a practice called coppicing has long historical roots, with the practice having been recorded in Egyptian and Roman times (Keoleian and Volk 2005). In coppicing, trees are cut at a young age (in the case of modern fuel production, typically at 3-4 years), and allowed to resprout from stumps. Any tree that sprouts from its stump (including most hardwoods) can in principle be raised this way. In practice, most research has been focused on the potential of willow (*salix* spp.), given its prolific sprouting habit, ability to resprout after multiple cuts, tolerance of dense planting, and fast growth (Keoleian and Volk 2005). There are also about 450 species of willow available around the world, from which preferred traits can be selected (Volk, Verwijst et al. 2004). There is also a smaller literature on using poplar as short rotation woody crop.

Willow plantings are semi-permanent. Plantings of cuttings typically require four years for establishment and growth before the first harvest. Thereafter harvests are made every three years, for a total seven harvests. Thus a willow stand is expected to last for 22 years.

At harvest, one pass with specialized equipment cuts and chips the young willow trees, which may be several meters in height. The resulting product is similar to forest-derived woodchips, and can be burned directly for energy. Storage and handling requirements of woodchips typically make them impractical to use on a small scale, i.e. woodchips are rarely used as a residential heating fuel. Typical use is in commercial or institutional heating plants (especially schools), and in electricity generating plants. Like forest woodchips, there is currently no practical (economical) way to dry willow chips; costs of handling and energy exceed gains from drying. Typically chips are burned “green” at

45%-50% moisture content. This reduces available energy from chips by about 45 % as compared to their dry potential (Maker 2004), perhaps a significant limitation compared to grassy crops like switchgrass, which can be dried in the field.

Though as noted above, production per hectare of willow chips can be several folds higher than for woodchips from the forest, willow chips are not currently in widespread use as a fuel, likely because of relatively high production costs. Tharakan et al. (2005) created a detailed model of willow production in New York state, for evaluation of willow as a fuel to cofire with coal in existing power plants. The model assumes three main actors: 1) farmers who choose to grow willow, in whole or in part as an eligible use of lands enrolled in the federal Conservation Reserve Program (CRP); 2) aggregators who assist farmers with specialized tasks and transport chips to users; 3) end users, who in this case are assumed to be power plants.

In this model the role of the aggregator is crucial. Given that willow stands are only planted on a 22-year cycle and only harvested and delivered to market on a three-year cycle, the assumption is that most farmers will not find it economical to own the specialized equipment required for these tasks. Thus the model assumes that the aggregator rents specialized equipment to the farmer, and provides for transportation of the harvest to the end user. The farmer is assumed to carry out tasks like mechanical cultivation, fertilization, and herbicide application (some of which may be required annually) with standard farm equipment.

Compared to fossil fuels, biomass fuel is bulky, and developing appropriate transportation logistics is key to successful biomass use. This issue is explored in greater depth in the regional economic impact analysis of the Massachusetts Sustainable Forest Bioenergy Initiative. For their model, Tharakan et al (2005) assume that willow growers will be located within an 80 km (~50 mile) radius from the power plants. This assumption is consistent with those made in the regional economic impact analysis.

Table 2 shows farm gate and plant gate (including transportation cost) prices predicted by Tharakan et al (2005), under four different combinations of assumptions. Prices are assumed to be the sum of total costs plus normal profits for both farmers and aggregators. The base case (1) assumes willow yields of 9.8 oven-dry tons/hectare/year until the first cutting, and subsequently 14.8 tons/hectare/year. Case 2 uses the same yields, but assumes the farmer gets payments through the Conservation Reserve Program (CRP), thus having lower costs that result in lower prices. Case 3 assumes increased yields through improved cultivars and cultivation techniques, and Case 4 assumes increased yields as well as CRP payments.

**Table 2, Price per green ton (converted from price per dry ton in Tharakan, 2005)**

| | farm gate price/ton | plant gate price/ton |
|---|---|---|
| Case 1: base yield | $24.04 | $32.34 |
| Case 2: base yield + CRP payment | 13.59 | 21.89 |
| Case 3: increased yield | 21.45 | 27.95 |
| Case 4: increase yield + CRP payment | 12.76 | 19.56 |

Model results suggest that willow chips may become economically attractive as a fuel. The base case, for example, predicts a plant gate price of $32.34 per green ton. In the regional impact analysis, we calculate an estimated equilibrium price for chips of $30.75 per green ton (assuming significant new demand and chip price increases due to construction of new biomass electric generating capacity). This suggests that even without subsidy, willow might soon enter the biomass supply market. And with CRP payments (case 2) a plant-gate price of $21.89 per green ton would be competitive in the current New England chip market.

Yet there are several reasons that willow chips may not quickly become a significant source of biomass fuel. Since there is little large-scale production of willow chips in the United States, all production cost estimates are unproven. One key assumption is willow yield; even the base case yield of 14.8 dry tons per hectare (after the first cutting) appears optimistic, for there is an enormous range in reported yields. Keoleian and Volk (2005) observe:

> "Experimental yields of short-rotation willow as high as 24 to 30 oven-dry tonnes (odt) $ha^{-1}yr^{-1}$ have been measured in Sweden and North America (Adegbidi et al., 2001; Christersson, 1986; Labrecque et al., 2003). Typical yields are more often in the range of 10 to 12 odt $ha^{-1}yr^{-1}$...Commercial yields have been considerably lower, about four odt $ha^{-1}yr^{-1}$, across almost 2,000 ha harvested in over a three-year period in Sweden (Larsson et al., 1998) and about six odt $ha^{-1}yr^{-1}$ in the first large-scale field trials harvested in New York in 2001 (Volk, unpublished data)."

Reduction in yields between experimental trials and actual production is widely observed, and thus not surprising. Yet with a recently commercialized crop like willow, research into improved strains and cultivation practices may also increase yields substantially. Differing yields would change production costs and prices, all else equal.

Another significant obstacle appears to be the simultaneous development of demand and proximate supply chains. The Tharakan model suggest the need for significant chip demand, at least enough to support one aggregator, and enough farmers to support one aggregator, and enough land in the CRP program to make the plant-gate chip price viable, all within a 50 mile radius of a plant. While such a system would appear to be sustainable, it is not clear how it would get established. One solution may be a more vertically integrated supply chain, as is widely practiced in poultry and some other industries (Hayenga, Schroeder et al. 2000). In this case a biomass-burning plant might contract for production of required crops, supply some or all of the required capital and specialized equipment, etc. This would reduce investment and market risk to farmers, and ensure a biomass supply of appropriate volume.

In summary, utilization of biomass from willow chips is clearly a technical possibility, and promises significantly greater energy production per hectare than forest woodchips. Yet willow also faces significant challenges, including realizing yields needed for financial viability, the practical requirement to utilize chips green (capturing much less than total energy potential), the need for specialized equipment in planting and harvesting willow, and the likely difficulty in simultaneously developing chip demand and supply.

**Perennial Grass Crop: Switchgrass**

Unlike willow and other short rotation woody crops, grass crops like switchgrass are harvested annually. Grass energy crops are similar in appearance and culture to conventional hay. And hay grasses can indeed be utilized for biomass energy, though they are not optimized for this purpose.

Unlike hay, switchgrass is normally harvested in the fall, or left to overwinter and be harvested in the spring. Delaying harvest allows more plant nutrients to return to the soil, and lowers ash content from about 5% in the fall to 3% in the spring (Samson 2007), though spring harvest also results in lower yields.

For either fall or spring harvest the switchgrass product is dried in the field. Switchgrass fuel typically has moisture content of 12%-15%, much less than the 45%-50% typical for willow chips, thus providing significantly more potential energy per ton. Yet handling of switchgrass is accomplished through baling in large round or square bales, and such bales are not easily used as a fuel.

Commercial and industrial-scale equipment can be designed to handle switchgrass as fuel directly; Qin et al (2006) reported on a scenario of using switchgrass for a power plant feedstock, and found that the most cost effective handling technique was harvesting switchgrass loose (no baling), and then "compression into modules" for transportation. Baled grass crops have also been used as a commercial fuel source in Europe (Cornell University 2007).

There is more literature, though, about converting switchgrass into pellet fuel. In this case the grass is shredded, then compressed and essentially extruded into pellet form. The resulting product is small, dry, pellets, comparable to wood pellets, and useable in a pellet-burning appliance designed to handle the relatively high ash content of biomass fuels, for example a stove designed to burn corn. The higher ash content of switchgrass, though, may result in a lower market price than for wood pellets, since higher ash content means more ash removal by the consumer.

Different sizes and configurations of grass pellet burning appliances are clearly a technical possibility, though few are currently available on the market (Cornell University 2007). In Canada in 2001, Jannnasch et al. noted that pellets were then burned almost exclusively in space heaters with less than 35,000 Btu/hr capacity.

Grass pellets can also have net energy advantages over wood pellets, since wood pellet manufacture sometimes involves drying  green woodchips, then mechanically reducing them to sawdust-level particle size before being extruded into pellets (Kingsley 2007). Neither of these energy-intensive steps is required to produce grass pellets.

As with willow, there is a wide range reported yields for switchgrass. The study shown in Table 3 used a yield figures of 3.99 short tons per acre, though other studies have found yields as high as 12.2 tons per acre (Kszos, McLaughlin et al. 2002). Switchgrass trial plots at UMass during the summer of 2007 suggested that Massachusetts can achieve yields similar to those assumed to be typical in Iowa.

Like willow, cost of switchgrass production is not entirely known, since production does not now occur on a large scale in the northeast. Table 3 shows an example of a switchgrass production budget, yielding a farmgate production cost of about $60/dry ton. Other studies have explored varying inputs and cultural practices for switchgrass, in different soils, to estimate a range of yields and final costs of the switchgrass product (Brummer, Burras et al. 2001; Kszos, McLaughlin et al. 2002; Nelson, Ascough et al. 2006).

Table 4 compares the net energy prices of green forest wood chips (based on assumptions used in the regional economic impact analysis of the Initiative), green willow chips, and dry switchgrass (before pelletizing). While under these assumptions willow chips are similar in price to forest chips, switchgrass appears significantly more expensive, even before pelletizing. Though switchgrass and willow can have similar yields per hectare (Table 1), there are several differences in switchgrass and willow production:

- Each hectare of switchgrass must be harvested annually, while willow is normally harvested only once in three years.

- Switchgrass harvest requires multiple passes for cutting and baling, while willow harvest is accomplished in one pass (though this also requires specialized equipment)

- Willow economics are calculated on a stand life of 22 years, while a switchgrass planting is normally assumed to last 10 years before replanting is required. Thus the initial planting investment is spread over fewer years for switchgrass production.

**Table 3, Switchgrass production cost budget example**

| | |
|---|---|
| **Pro-rated establishment & reseeding costs** | |
| | **$/hectare** |
| Total pro-rated establishment costs | 67.29 |
| | |
| **Pre-harvest machinery operations** | |
| spreading liquid nitrogen | 10.74 |
| applying P and K | 7.78 |
| spraying chemicals | 10.62 |
| Total machinery cost | 29.14 |
| | |
| **Operating expenses** | |
| N | 51.81 |
| P | 5.17 |
| K | 31.50 |
| Atrazine | 10.85 |
| 2,4 D | 6.04 |
| Total operating cost | 105.37 |
| Interest on op. expense @9% | 4.74 |
| | |
| **Harvesting expenses** | |
| mowing/conditioning | 21.98 |
| raking | 9.63 |
| baling | 160.14 |
| staging and loading | 64.31 |
| Total harvesting cost | 256.06 |
| | |
| **Land charge** | 123.46 |
| | |
| **Total production cost** | 586.06 |
| | |
| Yield per ha, Mg | 8.96 |
| Cost per Mg | 65.41 |
| Yield per acre, short tons | 3.99 |
| Cost per short ton | 59.46 |

source:Duffy and Nanhou (2002), Iowa

note: moisture content ≈ 12%

**Table 4, Fuel costs per MMBtu**

| | forest wood chips | coppiced willow chips | switchgrass |
|---|---|---|---|
| cost per ton, farmgate | | 24.04 | 59.58 |
| farm gate-plant gate cost | | 8.30 | 8.30 |
| cost per ton, plant gate | 30.75 | 32.34 | 67.88 |
| moisture content | 45% | 45% | 12% |
| MMbtu/ton | 9.25 | 8.77 | 13.75 |
| cost per MMbtu, plant gate | 3.32 | 3.69 | 4.94 |

Again, all costs for large-scale biomass crop production are somewhat speculative at this point. Qin et al. (2006), for example, estimated a non-pelletized switchgrass price of $32.53 per ton plant gate, similar to estimates in Table 4 for forest chips and willow chips (though Qin et al. do not provide detailed cost estimates, and the study appears to focus more carbon emission impacts than on production costs). Switchgrass and willow costs may in fact be more similar than suggested by the figures used in Table 4.

Switchgrass is native to North America and can be grown without any soil amendments. Yet where total cost as function of fertilizer inputs has been studied, total costs are generally minimized at higher levels of fertilizer use (Brummer, Burras et al. 2001; Nelson, Ascough et al. 2006). Some costs per hectare are constant regardless of yield level (land rent, mowing, etc.) and higher yields tend to reduce total costs, despite increased fertilizer expenditure. Brummer et al. (2001) estimated that a yield plateau for switchgrass occurred at between 56 and 112 kg/ha of nitrogen on the soils they studied. Municipal sewage sludge has been suggested as an appropriate fertilizer for biomass crops.

Thus the primary question is not whether switchgrass can be grown in Massachusetts, but what total yields can be obtained at what cost, i.e. what the switchgrass supply curve might look like. Graham et al. (1995) estimate switchgrass supply curves for different regions of the United States, including the northeast region. Assumptions for different biomass yields and production costs by soil type are modeled with data for land rents. Switchgrass production is assumed to occur when price is above break-even production cost on a particular land parcel, and total supply is calculated as the sum of yields on all land units on which production occurs. The authors note this is not a general equilibrium framework, i.e. if a significant quantity of land were removed from current crop production, prices for those crops would rise, effectively raising land rents and reducing the quantity of switchgrass produced at a given price. Thus results are only valid for small changes from current production.

Nelson et al. estimated switchgrass supply in Kansas using a similar approach, but in this case modeled production costs of alternative crop rotations (including different sequences of corn, soybean, wheat, and sorghum) and calculated net returns per acre for conventional and switchgrass crops under different production scenarios. Switchgrass production was assumed to occur when net returns were greater than for conventional crops.

While in principle a switchgrass supply curve could be estimated for Massachusetts, there are several key limitations:

- Switchgrass yield data for Massachusetts are scarce, though trials currently underway at UMass will provide some data.

- Yield response to fertilizer input must be estimated

- Yield data by fertilizer input for different soil types are needed. Yield data for less productive agricultural soils would be particularly useful, since prime agricultural soils are relatively scarce and perhaps less likely to be used for biomass energy crops than more marginal lands.

Experimental data of this sort for Massachusetts would be ideal. It may also be possible to estimate switchgrass response functions for different soil types based on a limited number of actual trials, and use of data for hay production on different soils, which is more readily available.

Another difficulty in estimating a supply curve is that most studies model prices at which farmers would switch production from other crops. While this would also happen in Massachusetts, the larger part of the potential supply is from use of currently idle farmland and from converting forests back to farmland, as described below. Modeling decisions on putting such land into production is more problematic than modeling crop switching decisions.

If switchgrass is utilized in pellet form, pelletizing is an additional production expense. The Grass Energy Collaborative (2006) reports pelletizing costs of $80-$85 per ton. Minimizing cost, however, may require a large scale: the report notes that a 100,000 ton per year plant could require a grass production area as large as 20,000 acres. Yet clearly pellets can also be produced on a much smaller scale. A number of small and portable pelletizing mills are currently available or under development (Cornell University 2007). In a survey of farmers, Jannasch et al. (2001) found that most preferred the option using mobile pelletizing units, which could reduce transportation costs. While a projection of retail grass pellet prices is beyond the scope of this study, given a base cost of perhaps $60 per ton production cost for switchgrass and $85 per ton for pelletizing, competing with wood pellets that currently retail for over $200 per ton appears possible. Again note that switchgrass pellets may command a somewhat lower price than wood pellets, given higher ash content.

Compared to forest and plantation wood chips, then, grassy biomass crops offer a practical way to provide a dry fuel, and thus effectively increase energy yield per hectare, though possibly at a higher cost than green wood chips. Switchgrass is relatively easily pelletized into a form that is in principle useable for smaller scale heating applications, though few appliances appropriate for burning grass pellets currently exist. Switchgrass can also be established and harvested with conventional farming equipment; a significant advantage over willow chips (though pelletizing grass fuels does require specialized equipment). Since grass pellets could be a useful fuel on a household or farm scale (unlike wood chips), the simultaneous development of demand and supply may be more easily accomplished with grass-based fuels than with short rotation woody crops.

**Other Biomass Crops**

Though this report focuses on willow and switchgrass, there are clearly a number of other potential biomass energy crops. Another short-rotation woody crop with potential in Massachusetts is poplar, with characteristics similar to willow. Other grass crops that will grow in New England include reed canarygrass and giant miscanthus; both have significant followings in the literature.

Corn is a crop with many uses, including shelled corn as solid fuel, a biomass crop already in use. Five Points Farm in Northfield, MA, produces over 1,000 tons of fuel corn per year, currently retailing for $170 per ton in bulk (UMass Extension 2007). On an energy basis this is comparable to oil at $1.75 per gallon, far below the current price of oil. Though corn may be an attractive fuel in the short term, it has several limitations compared to other crops discussed above:

- as an annual crop, corn production typically involves more tillage and soil erosion than perennial crops, and less carbon sequestration in farm soils (though no-till corn is also possible).

- compared to switchgrass, corn production is relatively energy intensive. Samson et al. (2005) estimate corn to require 2.9 GJ/tonne fossil energy input, while switchgrass requires only 0.9 GJ/tonne.

- corn is typically grown on the best available farmland, which is in limited supply in Massachusetts. For biomass production at a significant scale, less productive lands will likely be needed, and corn is not as well adapted to such lands as other crops.

Nationally, corn stover is also thought to have significant biomass potential (Perlack, Wright et al. 2005), though stover is less likely to be significant in Massachusetts. At the 2002 Census of Agriculture, Massachusetts ranked 44 of the 50 states in corn (for grain) production (USDA 2004), so stover is much less plentiful in Massachusetts than elsewhere.

**Possible Biomass Crop Demand and Supply**

Given that biomass crops potentially have high yields per hectare compared to forest biomass, and that some biomass crops may be economically grown in Massachusetts, additional questions are how much biomass energy might be needed, and how much land might be available to grow such crops. There is no simple answer to these questions. Below we assess possible demand for biomass fuel, and calculate land availability under three possible scenarios: 1) switching crops on existing farmland, 2) utilizing farmland not currently owned by farmers, and 3) converting former farmland, now reverted to forest, back into farmland. For each scenario we compare potential energy produced to possible demand.

Tharakan (2005) points out that land in the Conservation Reserve Program (CRP) is eligible for growing short-rotation woody crops, and a likely target for biomass production in New York state. But in Massachusetts, the 2002 Census of Agriculture reported only 17 farms with a total of 191 acres in both CRP and the Wetlands Reserve Program (USDA 2004). Clearly biomass acres will need to come from elsewhere.

*Possible Demand*

As noted above, we assume that the simplest way to utilize biomass fuel is as solid fuel for heating applications and for generating electricity. Though much research is underway on converting cellulosic biomass to more flexible forms, e.g. ethanol, the technology to do so is not currently available, and in any case conversion will come at a financial and energy cost. We further note that likely supply of biomass is less than demand for energy in solid fuel applications only, as shown below.

Massachusetts' residential and commercial use of coal and oil in 2004 was 140.7 trillion Btu (DOE Energy Information Administration 2004). The five western counties' share of this consumption was 35.0 trillion Btu, assuming the same per capita usage between the eastern and western Commonwealth. This represents energy that might be provided by biomass solid fuel. In addition, in the regional economic impact analysis we describe a plausible scenario for 165 MW of new biomass electricity generation, which would require 1.9 million tons of forest wood chips annually, or about 17.8 trillion Btu. We thus define "possible demand" as the sum of current 5-county coal and oil used in residential and commercial heating (not industrial), and in biomass electricity production as described:

current heating fuel + new biomass electricity generation =
35.0 trillion Btu + 17.8 trillion Btu = 52.8 trillion Btu

Note that "possible demand" could be much higher if it included other types of heating energy (notably gas), industrial energy uses, other fuels currently used for electricity production (coal, oil, gas), and/or transportation energy. Biomass might supply some of these uses in the future, though biomass supplies would not be adequate to satisfy all such needs at current demand levels (as illustrated below).

*Supply Scenario I: Crop Switching*

A supply curve for biomass crop production indicates what quantities of crops could be expected at different prices per ton, in part as a result of farmers switching crops on existing acreage. Absent such a supply curve (as discussed above), we use a simpler approach for illustration only. Table 5 shows Massachusetts farms by NAICS classification, sorted by acreage (USDA 2004). Note that farms are classified by primary product only, though many farms may in fact produce multiple goods. Various combinations of biomass price increases and changes in prices for other crops could make it beneficial for farmers to switch to biomass crop production. For example, if a hypothetical 20% of all existing agricultural land in the 5-county region were converted to biomass energy crops, this would amount to approximately 67,000 acres, supplying an estimated 5.3% of potential solid fuel demand (Table 6).

**Table 5, Massachusetts farm types by NAICS code, sorted by acres**

| Farm type | Farms | Land in farms (acres) |
|---|---|---|
| Hay farming (11194) | 962 | 121,099 |
| Dairy cattle and milk production (11212) | 279 | 92,040 |
| Fruit and tree nut farming (1113) | 811 | 72,240 |
| Other animal production (1129) | 1,188 | 45,229 |
| All other crop farming (11199) | 296 | 40,368 |
| Beef cattle ranching and farming, including feedlots (11211) | 424 | 37,722 |
| Greenhouse, nursery, and floriculture production (1114) | 958 | 35,853 |
| Vegetable and melon farming (11121) | 469 | 34,737 |
| Oilseed and grain farming (1111) | 81 | 13,780 |
| Sheep and goat farming (1124) | 211 | 10,223 |
| Poultry and egg production (1123) | 163 | 5,094 |
| Hog and pig farming (1122) | 72 | 4,960 |
| Tobacco farming (11191) | 37 | 3,497 |
| Animal aquaculture (1125) | 124 | 1,728 |
| **Total** | 6,075 | 518,570 |

*Supply Scenario II: Using Farmland not Currently Owned by Farmers*

Western Massachusetts has clearly experienced a decline in farming over the last century; abandoned farm fields are readily apparent in much of the region. Biomass crops may be a good candidate for such fields, especially where current (non-farmer) owners are using resources to mow fields to prevent reversion to forest. In such cases owners may be managing simply to maintain an agricultural landscape, or perhaps to preserve the option of using land agriculturally in the future. The land's actual production may have low value to its owners, and production value may actually be negative if funds are expended for mowing. One can imagine that nearby farmers could utilize such land for biomass production, if markets were available. This would provide a service to landowners who want open land, and provide farmers with low (possibly zero) rent on land used for biomass crop production.

**Table 6, Supply scenario summary**

| | Scenario 1: 20% of all farmland converted | Scenario 2: idle farmland put into use (max) | Scenario 3: additional 20% of land area converted to farming |
|---|---|---|---|
| farm acres | 66,968 | 59,694 | 566,959 |
| farm biomass tons/ acre | 3.0 | 3.0 | 3.0 |
| farm biomass million Btu/ton | 14.0 | 14.0 | 14.0 |
| forest acres lost | - | - | 566,959 |
| forest biomass/acre | - | - | 1.1 |
| forest biomass million Btu/ton | - | - | 9.3 |
| net trillion Btu supply | 2.8 | 2.5 | 18.1 |
| possible solid fuel demand, trillion Btu* | 52.8 | 52.8 | 52.8 |
| percent of potential demand met | 5.3% | 4.7% | 34.4% |

*based on current residential and commercial heating demand, and biomass electricity production as projected (see text above)

Since owners' objectives obviously vary, it is impossible to say exactly how much land meeting this description might exist. But we can obtain an upper bound estimate by comparing the amount of land with agricultural characteristics to the amount of land owned by farmers. We use 1990 GIS data for the five-county area, based on satellite imagery, to identify farmland, in this case land classified as pastureland, cropland, and perennial cropland. We also get similar data from the 1997 and 2002 Censuses of Agriculture (USDA 2004), interpolating to estimate 1999 quantities. Note that Census data only include land owned by farmers, defined as those who sell (or would normally sell) more than $1000 of agricultural products in a year. Thus the difference represents farmland not owned by active farmers. Viewed from a satellite, though, agricultural land includes acreage used by individuals for home and hobby production, institutional acreage, etc., not all of which would be available for biomass production. Hence this estimate represents only an upper bound, a maximum amount of farmland not owned by farmers that might be available. As shown in Table 7, the quantity of such non-farmer owned farmland in the five-county region is 59,694 acres, which could produce 2.5 trillion Btu or 4.7% of potential regional demand for solid fuel (Table 6).

**Table 7, Farmland not owned by farmers**

| | Berkshire | Franklin | Hampden | Hampshire | Worcester | 5-county |
|---|---|---|---|---|---|---|
| GIS data, 1999, agriculture-pasture | 15,786 | 11,822 | 6,226 | 9,096 | 18,927 | 61,857 |
| USDA Census-1999 estimate, pastureland | 3,907 | 4,048 | 1,673 | 3,123 | 6,903 | 19,654 |
| pastureland not in use by farmers | 11,879 | 7,774 | 4,553 | 5,974 | 12,024 | 42,204 |
| GIS data, 1999, agriculture-crop | 34,651 | 28,891 | 15,853 | 29,988 | 45,243 | 154,626 |
| GIS data, 1999, agriculture-perennial | 683 | 2,113 | 1,931 | 1,350 | 4,980 | 11,057 |
| USDA Census-1999 estimate, total cropland | 29,495 | 30,649 | 17,088 | 27,464 | 46,370 | 151,065 |
| USDA Census-1999 estimate, idle cropland | 328 | 679 | 788 | 384 | 694 | 2,873 |
| cropland not in use by farmers | 6,168 | 1,033 | 1,484 | 4,258 | 4,548 | 17,490 |
| total agricultural land not in use by farmers | 18,047 | 8,807 | 6,037 | 10,232 | 16,571 | 59,694 |

*Supply Scenario III: Converting Forestland to Farmland*

As noted above, land in Massachusetts has changed steadily since colonial settlement. Land that was mostly deep forest when the settlers arrived was slowly but surely cleared for agriculture, though the specific crop mix changed significantly over the centuries (Russell and Lapping 1982). But as the country expanded and better farmland became available to the west, farms were abandoned, and forests gradually retook the cleared land. Thus much of Massachusetts' current forest cover is of relatively recent vintage, and occupying former farmlands.

We can estimate the magnitude of such changes from the Census of Agriculture, which was first conducted in 1850, and has taken place at approximately five-year intervals ever since. As shown in Table 8, farmland of various kinds accounted for 47% of total land in the 5-county area at the 1905 census. By the 1954 Census, this had dropped to 24% of land area, and by the 2002 census, farmland covered only 5% of total land area in western Massachusetts (though note that farmland measured by satellite imagery was 8% of land area in 1999). Thus a massive change in land use has occurred over one century.

How much of this land could be feasibly returned to agricultural production is a question that requires much more study. Some former farmland is ecologically sensitive, for

**Table 8, Historic farmland changes in Massachusetts**

| | Berkshire | Franklin | Hampden | Hampshire | Worcester | 5-county |
|---|---|---|---|---|---|---|
| TOTAL LAND AREA | 605,673 | 463,720 | 405,783 | 348,960 | 1,010,659 | 2,834,795 |

**1905 Census**

| | Berkshire | Franklin | Hampden | Hampshire | Worcester | 5-county |
|---|---|---|---|---|---|---|
| hay | 130,067 | 61,351 | 52,957 | 61,930 | 168,767 | 475,072 |
| farm crops | 20,205 | 12,288 | 17,231 | 16,915 | 29,266 | 95,905 |
| market gardens | 836 | 382 | 1,450 | 808 | 3,165 | 6,641 |
| nurseries | 13 | 18 | 43 | 9 | 45 | 128 |
| orchards | 2,567 | 3,168 | 3,176 | 2,490 | 9,572 | 20,973 |
| seed gardens | 51 | 1 | 25 | - | 49 | 126 |
| other cultivated | 209 | 1,858 | 2,217 | 2,846 | 1,244 | 8,374 |
| permanent pasture | 150,234 | 126,641 | 88,184 | 104,546 | 252,076 | 721,681 |
| TOTAL FARMLAND | 304,182 | 205,707 | 165,283 | 189,544 | 464,184 | 1,328,900 |
| % TOTAL LAND | 50% | 44% | 41% | 54% | 46% | 47% |

**1954 Census**

| | Berkshire & Franklin (1) | | Hampden & Hampshire (A) | | Worcester (B) | 5-county |
|---|---|---|---|---|---|---|
| cropland, total | 123,743 | | 98,273 | | 131,843 | 353,859 |
| land pastured, total | 139,567 | | 77,390 | | 118,374 | 335,331 |
| TOTAL FARMLAND | 263,310 | | 175,663 | | 250,217 | 689,190 |
| % TOTAL LAND | 43% | | 43% | | 25% | 24% |

**1999 GIS data**

| | Berkshire | Franklin | Hampden | Hampshire | Worcester | 5-county |
|---|---|---|---|---|---|---|
| agriculture - crop | 34,651 | 28,891 | 15,853 | 29,988 | 45,243 | 154,626 |
| agriculture - pasture | 15,786 | 11,822 | 6,226 | 9,096 | 18,927 | 61,857 |
| agriculture - perennial | 683 | 2,113 | 1,931 | 1,350 | 4,980 | 11,057 |
| TOTAL FARMLAND | 51,120 | 42,825 | 24,010 | 40,435 | 69,150 | 227,540 |
| % TOTAL LAND | 8% | 9% | 6% | 12% | 7% | 8% |

**2002 Census**

| | Berkshire | Franklin | Hampden | Hampshire | Worcester | 5-county |
|---|---|---|---|---|---|---|
| total cropland | 25,701 | 25,998 | 15,554 | 23,758 | 42,365 | 133,376 |
| pastureland | 5,505 | 4,461 | 1,753 | 3,511 | 6,094 | 21,324 |
| TOTAL FARMLAND | 31,206 | 30,459 | 17,307 | 27,269 | 48,459 | 154,700 |
| % TOTAL LAND | 5% | 7% | 4% | 8% | 5% | 5% |

example wetlands. Some has been developed for urban and suburban use. Some was cleared for pasture, but is too steep or rocky to be useable by modern agricultural machinery. And of course landowner and public preferences for farmland vs. forestland have not been systematically assessed. In some cases, an increase in open land may be welcome, while in others, forest will likely be preferred. But for illustration, we arbitrarily pick a figure of 20% of 5-county land area that might be converted from forest to biomass crop production, or a re-conversion of about half the farmland lost since 1905. Current farmland is 8% of land area (GIS data), so this re-conversion would increase total farmland to 28% of land area. In this scenario, biomass production increases by 18.1 trillion Btu, or 34.4% of potential demand for solid fuel (Table 6). Note that land converted from forest to farmland would no longer be producing forest biomass. But as discussed above, agricultural biomass production is likely much higher per acre than forest production. Thus a significant on-going increase in total biomass production can be accomplished through land conversion. There would also be a large one-time increase in biomass production when land was cleared (not calculated here).

**Summary**

If future energy sources are to be renewable and carbon free, energy from biomass will almost certainly play a significant role. As should be clear from the discussion above, biomass is a particularly land extensive energy source: to supply a significant portion of today's energy use, large land areas are required. This suggests that care be exercised in evaluating all aspects of land use related to biomass production: ecological, economic, aesthetic, etc.

Perennial biomass crops have the potential (albeit largely unproven) to produce much larger quantities of energy per hectare than forest biomass, and thus are of interest for increasing future biomass supply. Biomass crops also hold several attractions for the particular situation of Massachusetts:

- biomass crop production could sustain and reinvigorate the agricultural economy;
- some biomass crops (particularly grassy ones) can create traditional agricultural landscapes;
- some land owners now incur expenses mowing fields simply to maintain them, and such areas could be used to produce biomass crops;
- some biomass crops (again, particularly grassy ones) are adapted to smaller scale production, as is currently found in many parts of Massachusetts;
- biomass is by its nature bulky and difficult to transport—if Massachusetts is to use biomass energy, most of it must come from nearby.

While biomass energy crops hold much potential, a biomass crop industry has not yet emerged. Such an industry is likely to serve at least two different markets: chips from short rotation woody crops for institutional heating and electricity generation, and pellets from perennial grass crops for smaller-scale heating applications. In both cases supply and demand need to be developed simultaneously.

There are also a number of key research needs for biomass energy crops:

- Conducting field trials on biomass crops in Massachusetts, to determine optimal crops and production practices for Massachusetts. Trials on marginal agricultural land are of particular interest.

- Developing a biomass crop supply curve: this depends on better yield data and yield response to inputs, particularly on lands of marginal productivity that are most available for biomass production. A spatial model of likely supply and demand points would also be useful.

- Learning more about the potential for forestland conversion to biomass crop production: this would include estimating potential biomass crop yields on currently forested land, assessing ecological impacts and land availability, estimating land conversion costs, and researching public and landowner attitudes toward land conversions at different levels.

- Assessing key infrastructure and development needs for a biomass energy crop industry, and the extent to which these might be provided by the free market, or need government assistance to achieve socially optimal outcomes.

Biomass energy clearly will clearly be important for future generations of the Commonwealth. A priority for the current generation is to fully understanding biomass potentials and impacts, so that an appropriate energy path can be chosen.

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