Woody Biomass Supply, Economics, and Biofuel Policy

Maine and Northeastern Forests

Jonathan Rubin, Binod Neupane, Stephanie Whalley, and Sharon Klein

The amount of woody biomass available for biofuel production depends on tree growth rate, harvesting techniques, harvest cost, government policies, and established traditions within the industry. Comparing estimates of biomass availability across studies is difficult because of different methodologies for estimating biomass supply, compounded by inconsistent and often unspecified assumptions. Studies differ in their definition of biomass (i.e., tree size, parts of tree) and consideration of ecological and economic factors (i.e., harvest productivity and costs, competing demand, compliance with existing regulations). In particular, existing restrictions on biomass harvesting for biofuels under the Federal Renewable Fuel Standard often are not included. Additionally, because most biomass availability studies ignore current biomass uses, an overestimation of available biomass for future uses results. Presented are new estimates for the amount of economically available biomass in Maine, taking into consideration both economic (integrated harvesting for pulp and precommercial thinning) and ecological factors. It is found that biomass availability varies greatly, depending on the relative location of the biorefinery, biomass harvesting site, and existing wood consumers (e.g., pulp mill). Indeed, harvesting and transporting woody biomass without an existing use for the high-value forest products (saw logs and pulp) probably makes woody biomass for energy production uneconomical. This finding is contrary to some existing studies and suggests that economic consideration needs greater emphasis in estimating biomass availability for biofuels.

Despite recent progress in producing more petroleum domestically, a national push continues for more liquid transportation fuels, particularly drop-in biofuels from cellulosic sources. The motivation is driven by the twin financial and security goals of reduced reliance on imported fuel as well as the desire to reduce greenhouse gas emissions from the transportation sector. The U.S. Renewable Fuel Standard (RFS) was authorized by the Energy Policy Act of 2005 and later expanded and revised under the Energy Independence and Security Act of 2007 (EISA) into a fuel volume mandate (known as RFS2) for several types of biofuels. The RFS2 requires the use of increasing amounts of renewable fuels in the nation's transportation sector primarily through blends with petrogasoline and petrodiesel, but also, it is anticipated with infrastructure-compatible drop-in biofuels. The overall goal is 36 billion gal of biofuel by 2022, with increasing annual amounts of advanced biofuel (i.e., not ethanol derived from corn starch) with life-cycle greenhouse gas emissions at least 50% less than baseline emissions [PL 110-140 Title II (A) § 201 (B)]. The EISA effectively caps the quantity of corn-based ethanol at 15 billion gal in 2015, by mandating that the future yearly increasing volume requirement be composed of advanced biofuels.

To ensure compliance with RFS2 and to encourage the growth in renewable fuels, the Environmental Protection Agency (EPA) assigns renewable fuel producers or importers (e.g., sugarcane ethanol) a renewable identification number (RIN) for every gallon of biofuel produced. There are separate RINs for each of the four categories of renewable fuels (renewable biofuels, advanced biofuels, cellulosic biofuels, biodiesel) within a hierarchy in which the cellulosic and advanced biofuel RINs can be used for compliance with overall renewable fuel mandates, but the submandates for cellulosic and biodiesel RINs cannot be met by renewable biofuel and advanced biofuel RINs [see McPhail et al. (*1*)]. The RINs are separated from the fuel when the renewable fuel enters the market, becoming a credit that can be bought and sold. RIN market values are determined by their supply and the need of petroleum fuel suppliers and importers to have RIN credits to demonstrate compliance with RFS2. RIN prices can vary greatly depending on complex market interactions that involve petroleum fuel markets, tax incentives for biofuels, expectations of RIN availability, and EPA's actions to set future advanced biofuel volume targets. Since the beginning of the program, corn ethanol RIN credits have consistently ranged between $0.01/gal to $0.05/gal, much lower than biodiesel RIN prices, which were in the $1.00 to $1.50 range. Beginning in early 2013, corn ethanol RIN prices began to increase sharply, reaching highs of around $1.00/gal before both RIN credits prices dropped to about $0.60 in March 2013 (*2*).

In 2013, the United States consumed around 13.18 billion gal of ethanol (*3, 4*). Ethanol in the United States is still almost exclusively made from corn (~95%) and sugarcane (~5%), and there is a small amount (~800,000 gal) of biofuel (ethanol and diesel) from cellulosic sources (*3, 5*). To date, there is no commercial production of biofuels from woody biomass. Possible pathways for drop-in fuel include pyrolysis of biomass followed by hydroprocessing and biofine process followed by thermodeoxygenation (*6, 7*). Since biofuels must compete with petrofuels in the marketplace, their economic viability is primarily dependent on feedstock availability and costs, government incentives that support fuels from biomass, the value of coproducts, and capital costs. Other costs, such as chemicals used in the production process (e.g., sulfuric acid) and feedstock storage, are also important to a lesser extent. In addition, key ecological considerations, such as soil productivity, water quality, and forest biodiversity affect economic viability (*8, 9*).

The goal of this study is to estimate biomass availability from Maine and Northeastern forests, taking into consideration ecological

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J. Rubin, Margaret Chase Smith Policy Center, 302C Winslow Hall, and B. Neupane, S. Whalley, and S. Klein, 305 Winslow Hall, School of Economics, University of Maine, Orono, ME 04469. Corresponding Author: J. Rubin, rubinj@maine.edu.

Transportation Research Record: Journal of the Transportation Research Board, No. 2502, Transportation Research Board, Washington, D.C., 2015, pp. 108–115.
DOI: 10.3141/2502-13

restrictions, RFS2 regulations, and other economic factors. As part of this analysis, examined are the impacts of the relative location of the biofuel refinery, biomass harvesting site, and existing wood consumers (e.g., pulp mill) on the economic viability of available biomass.

LITERATURE REVIEW

Most biomass availability estimates, including this one, are based on Forest Inventory Analysis (FIA) data (Table 1), except for the U.S. Department of Energy's Billion Ton Report (BTR), which uses other national data. The Laustsen study uses Maine Forest Service data in addition to FIA data (*10*). Since different studies report green or dry tons, green tons (GT) were converted to dry tons (DT) by assuming a 50% moisture content, that is, 1 DT equals 2 GT. FIA data defines timberland as nonreserve forest land capable of producing a minimum of 20 ft^3 of wood per acre per year. Ninety-seven percent of Maine forest land is classified as timberland, though not all timberland is necessarily suitable for harvesting. An FIA state forest inventory is completed every 5 years using sample plots. Stand characteristics such as forest type, land use, and ownership type are also recorded. The FIA database provides the status and trends in a given forest area by tree species, size, volume, growth, mortality, and removals.

Wharton et al. used FIA data between 1980 and 1983 to estimate the total above ground tree biomass in Maine at approximately 750 million DT, including growing stock bole used for pulp or saw logs, tops and branches, saplings, cull, and salvageable dead trees (*11*). Wharton and Griffith reported nearly 700 million DT of timber biomass, including cull trees, branches, foliage, stumps, and roots;

TABLE 1 Summary of Biomass Availability Studies in Maine

Study	Date	Data Source	Biomass Components Considered	Dry Tons (thousands)	Biomass Retention[a] (%)
Wharton et al. (*11*)	1985	FIA	Growing stock bole	382,500	NA
			Tops and branches	150,000	NA
			Saplings[b]	112,500	NA
			Cull trees[c]	82,500	NA
			Salvageable dead trees	15,000	NA
			Total	750,000	NA
Wharton and Griffith (*12*)	1995	FIA	Timber (growing stock bole, growing stock branches, foliage, stumps, roots, and cull trees)	699,113	NA
			Salvageable dead trees[d]	11,887	NA
			Saplings	149,572	NA
			Seedlings[e]	29,630	NA
			Shrubs	10,298	NA
			Total	900,499	NA
McWilliams et al. (*13*)	2003	FIA	Timber (growing stock bole, growing stock tree branches, foliage, stumps, roots, and cull trees)	777,346	NA
			Salvageable dead trees	11,505	NA
			Saplings	182,038	NA
			Shrubs	9,638	NA
			Total	980,526	NA
Laustsen (*10*)	2008	FIA	Tops and branches, cull, salvageable dead trees, and saplings	6,600	NA
Maine Forest Service (wood-to-energy task force) (*15*)	2008	FIA	Tops and branches	900	33
			Cull trees	895	50
			Salvageable dead trees	200	50
			Saplings	550	85
			Total	2,545	NA
Perlack et al. (*16*)	2005	TPO	Logging residues	2,225	30
			Other removals	26	30
			Fuel treatment thinning (timber land)	1,860	30
			Unused primary mill residues	41	30
			Total	4,153	30
Perlack and Stokes (*17*)	2011	TPO	Logging residues (tops, branches, and limbs, salvageable dead trees, rough trees, and rotten trees)		
			at $20/dry ton	585	30
			at $30/dry ton	2,584	30
			at $40/dry ton	2,739	30
			at $50/dry ton	2,739	30
Current study	2014	FIA	Limbs and tops	2,366	33
			Cull trees (rough and rotten)	354	50
			Saplings	1,181	85
			Total	3,902	NA

NOTE: NA = not available; TPO = timber product output.

[a] Biomass left in the forest. Under best management practice, this retention is required for forest soil, wildlife habitat, and biodiversity.

[b] Saplings are trees between 1.0–4.9 in. diameter at breast height (DBH) (*17*).

[c] Cull trees are live trees—5 in. in diameter at breast height or larger—that is, nonmerchantable for sawlogs now or prospectively because of rot, roughness, or species (*17*).

[d] Salvable dead trees are trees with intact bark. These trees are assumed to contain sound wood and are treated in the same way as cull trees (*14*).

[e] Seedlings are trees smaller than 1.0 in. (*14*).

and nearly 200 million DT of nontimber biomass (salvageable dead trees, saplings, seedlings, shrubs) (*12*). McWilliams et al. estimated 777 million DT of timber biomass (including same components as Wharton and Griffith) and 203 million dry tons of nontimber biomass, based on FIA data between 1998 and 2003 (*13*). Consistent terminologies are used as long as they refer to the same biomass component. For example, Wharton et al. used the term merchantable stem for bole component of growing stock tree (*11*). In addition, some biomass components are aggregated into a broader category in some reports, while others break down the components. For example, Wharton and Griffith (*12*) and McWilliams et al. (*13*) aggregated growing stock bole, growing stock branches, foliage, stumps and roots, and cull trees into timber category whereas Wharton et al. break down these components (*11*). None of these three reports considers the need to retain a certain amount of biomass in the forest for biodiversity and ecosystem health.

Laustsen published a report on potential available biomass volume for existing pulp and paper mills in Maine using different approaches (*10*). One approach presented in Table 1 assumes that additional biomass is obtained through existing harvest operations. Using 2003 FIA data, the report estimates that each existing mill (total 13 mills) could potentially access 0.3 to 1.9 million DT, resulting in a total maximum availability of 6.6 million DT per year within Maine (*14*). The other approach uses wood baskets with an approximate 60-mi radius that includes Maine and some parts of New Hampshire. The estimates range from 0.9 to 3.0 million DT for each mill and suggest a total available annual biomass volume of 6.4 million DT (*10*).

In 2008, the Wood-to-Energy Task Force concluded that with improvement in forest utilization and silviculture, Maine's forests could produce substantially more biomass than current harvest (tops and branches, cull trees, salvageable dead trees, and saplings) while still maintaining forest ecosystem health (*15*). In particular, the Wood-to-Energy Task Force determined that Maine's forests could produce 1.9 million additional DT per year net of current use (*15*). The additional production would be from improved harvest of current stands, harvest in stands not previously considered commercially viable (thinning of overstocked stands), more intensive management, and increased imports from outside Maine. This estimate does take into account sustainability concerns such as soil productivity, water quality, and maintaining biodiversity. However, this estimate does not take into account the economic feasibility of extracting, transporting, and using the additional resources.

The Department of Energy's estimate for Maine is part of a national estimate of biomass supply for bioenergy and bioproducts, widely known as the billion ton report (BTR) (*16*). The BTR concludes that the nation has the capacity to produce at least 1 billion DT of biomass annually from agricultural and forest resources in a sustainable manner. The forest resources include residues from the following operations and sources: conventional logging, forest management and land clearing, fuel treatment thinning, primary and secondary wood processing mills, pulping liquors (black liquor), urban wood removal, tree trimming, packaging wastes and consumer durables. The report estimates about 4.1 million DT of available biomass in Maine.

The BTR was updated in 2011 with new data and assumptions and, in particular, biomass estimates that vary with price per delivered ton (*17*). The billion ton report update (BTRU) uses 2009 U.S. Department of Agriculture's agricultural projections and 2007 Resources Planning Act Assessment and Timber Product Output data. The BTRU treats logging residue as a residual product as part of a whole-tree harvest in which the entire tree is dragged to the roadside, such that the only costs will be for stumpage and chipping at roadside. The chipping costs were determined using the Fuel Reduction Cost Simulator model (*18*). The report assumes 30% retention of logging residues on slopes less than 30%, and 50% retention on steeper slopes, to estimate of the amount of material needed to maintain productivity, biodiversity, carbon sequestration, and to prevent erosion and soil compaction. The report estimates approximately 2.7 million DT of logging residues at $50/DT delivered to the roadside in Maine.

The logging residues in the BTRU and in estimates in this study deserve special attention given their economic attractiveness. In the BTRU, residues consist of tops, branches and limbs, salvageable dead trees, rough and rotten trees, noncommercial species, and small trees. There are two major sources of residues from forest stands: limbs, tops, cull trees, and cull tree components, and downed trees from harvesting operations (logging residues); and the non-merchantable components of stands that are thinned as part of fuel treatments and restoration harvests (thinning). These two forest biomass resources only come from nonreserve forestland, which is land that is not removed administratively or designated as roadless. Conventionally sourced wood is biomass that is derived from additional operations to provide pulpwood-sized roundwood for bioenergy applications. This biomass has a commercial value other than for energy purposes, but it is used as an energy feedstock because of competitive market conditions. This conventional wood was not included in the 2005 BTR.

Beyond Maine, in general, the northeastern region of United States has a great potential to supply biomass for energy use. Buchholz et al. reported a total of 4.2 to 17.4 million DT per year of dry forest biomass depending on scenarios that could be available for energy use in eight Northeastern states: Connecticut, Maine, Massachusetts, New Hampshire, New York, Pennsylvania, Rhode Island, and Vermont (*19*). The BTR report estimates about 74 million DT per year in the Northeast. While estimating these figures, the study assumed that 50% of tops are removed. Fallon and Breger estimated a total of 4.4 million tons of dry woody biomass could be harvested annually in Massachusetts (*20*). In New York, Wojnar et al. estimated that 5.8 to 7 million DT of biomass per year, depending on scenarios, are available without competing with current uses (*21*).

Beyond the level of biological availability is the issue of biomass not brought to the road side whether cut down or left standing. Biomass may be retained within the forest for economic and technical reasons, for the ecological health of the forest pertaining to habitat preservation, and, in Maine in particular, to meet Maine's water quality best management practices (*22, 23*). The importance of forest biomass retention has become increasingly prominent, with national focus on using biomass for energy production, in addition to the traditional uses of the bole in paper and lumber industries and biomass chips to produce electricity owing to concerns that a larger market for biomass may lead to the unsustainable removal of logging residues. The amount of biomass retained on site depends on the harvesting method used, presence of a market for biomass chips, and site and weather conditions associated with soil erosion. In the Northeastern region, the Forest Guild Biomass Working Group recommends retaining one-fourth to one-third of the slash, tops and limbs from harvest.

The authors are particularly interested in the level of biomass residue left on site after harvest because of the impact on biomass availability. As shown in Table 1, previous biomass availability studies have used a variety of biomass retention assumptions ranging from not considering it to retaining as much as 85% depending on the specific type of biomass (e.g., saplings). The BTR and BTRU assume that 30% of logging residues are retained in the forest with larger amounts on steeper slopes. The Maine Forest Service report assumed 33% retention level for tops and branches, 50% for cull trees, and 85% for saplings. Buchholz et al. assumed 50% retention for tops in their estimates (*19*). The State of Minnesota suggests leaving one-third of fine wood material on site, while Pennsylvania recommends leaving 15% to 30% of total harvested biomass as coarse woody material. To address how current biomass retention practices in Maine, Briedis et al. reported results from 12 whole-tree harvest sites as part of an integrated roundwood and energy-wood whole tree harvest (*22*). They found that mechanical limitations of existing equipment, in addition to adherence to best management practices for water quality and forest ecosystem protection, resulted in 45% of total residue material left on site. This implies a tree top and branch removal rate of 55%. Reviewing these various assumptions and limited data, it is clear that there is no consensus on the amount of biomass that should be retained owing to practical harvesting mechanics or ecological considerations. It is also clear that biomass retention rates are an important consideration to estimate actual biomass availability.

APPROACH TO BIOMASS AVAILABILITY ESTIMATION FOR MAINE

An absolute availability was estimated of limbs and tops, saplings and unmerchantable cull biomass in Maine, by using recent FIA data between 2009 and 2013. The relevant data were retrieved from the FIA's national program with the associated EVALIDator software developed by the Northern Research Station, U.S. Department of Agriculture's Forest Service. EVALIDator is a Visual Basic Application linked to the FIA database; it generates and reports various types of estimates, including forest area, number of trees, growing-stock volume, growth, removals, and mortality (*24*). Retrieved were required tree count, growing stock, and removal tables from the EVALIDator within the specified radius. Equations from Jenkins et al. were used (*25*) to convert volume into DTs for each component of trees. The components of tree biomass for merchantable stem, stem bark, and foliage biomass are calculated as proportions of the total aboveground biomass. Top and branch biomass are calculated as a residual after subtracting stem and foliage biomass from total aboveground biomass.

The final biomass was broken down into limbs and tops, unmerchantable cull trees, and unmerchantable sapling biomass. Estimated were a total of 3.9 million DT of biomass that can be harvested sustainably year after year from timberlands of Maine. This is an absolute availability of unmerchantable biomass in growing stock as a proportion of inventory and unmerchantable biomass in cull. As shown in Table 1, the total estimates are lower than all other estimates, except for the BTRU. The BTRU estimates are lower than the total estimate in this study because only the logging residues biomass are considered in the BTRU. However, when comparing the BTRU logging residues with this study's estimate for limbs and tops, one sees that the BTRU logging residues are greater. As discussed, the BTR and BTRU estimates use different data sources from those of the current study, and the BTRU considers cost function while this study's estimates do not consider harvesting costs. However, the BTR and BTRU reports likely significantly overestimate the amount of biomass that is economically available, since they do not take into account existing uses of biomass, and use an unrealistically low cost of biomass harvesting costs based only on chipping costs. Like the BTR and BTRU reports, the estimate in this study itself is likely an overestimate of the economically available biomass, since some of the statewide available biomass is in remote locations. The estimates differ from those of Wharton et al. (*11*), Wharton and Griffith (*12*), and McWilliams et al. (*13*) in regard to biomass definition and biomass retention. Those studies reported the total above ground biomass and do not provide information about how much biomass could be harvested annually, while the current estimate provides sustainable availability of biomass. The Laustsen report estimates do not break down biomass components and has higher estimates than the current one, since it did not account biomass retention (*10*).

Current Biomass Use

Forest biomass in Maine is mostly used in wood-fired electricity plants and cogeneration facilities at the pulp and paper mills. In addition, biomass is used as a heating source for community service institutions, such as schools and for residential space heating via wood pellets. Currently, Maine has five operating utility-scale biomass plants, all generating renewable electricity, and 10 pulp and paper mills that have biomass energy plants (*26*). Nearly all this biomass demand is met within Maine. In 2012, the biomass harvesting volume was 1.2 million DT, and biomass energy facilities consumed 1.3 million DT of biomass in Maine (*27*). Out of this consumed biomass, 85% was produced in Maine, and the remaining was imported. Additionally, other industrial plants used more than 1 million DT of wood waste and sawmill residues for electricity generation for their facilities. The North East State Foresters Association reported that wood pellet manufacturing plants in Maine consume an estimated 200,000 DT of feedstock raw material (*26*). Additionally, 300,000 DT of woody biomass is used for firewood, chips, and pellets to heat homes or businesses annually in Maine (*26*). Wood use for heating by using wood chips and wood pellets continue to grow in Maine. The demand for biomass for wood energy is expected to grow in the future as new pellet mills, torrefaction mills, and biorefineries under construction start production. Figure 1 shows the current biomass use by wood energy sector in Maine. Figure 2 shows the pulp and paper mills in Maine and neighboring states.

Prices paid for this biomass are generally proprietary, but the Energy Information Administration does estimate state-level, total end-use energy prices and expenditures (*29*). After adjustment for the energy density and moisture content appropriate for Maine, these data show that other users of biomass paid $29 to $45/GT ($2012) over the 2001 to 2012 period. Additionally, the only published report that the authors know of states that biomass sells for $25/GT (*30*). A follow-up to the lead author suggests that the range (generally known in the industry) is from $25 to $35/GT (J. Benjamin, personal communication, Feb. 3, 2015).

RFS2-Compliant Biomass Harvest

As mentioned earlier, because of national policy goals of expanding the production of biofuels, biofuel producers who produce biofuel from renewable biomass are eligible to generate a biofuel credit.

All prior biomass availability estimates for Maine do not take into account the "renewable biomass" definition under the RFS2. If forest biomass is to be used to produce biofuel that contributes to RFS2 volume mandates, it must qualify as renewable biomass for RIN credits

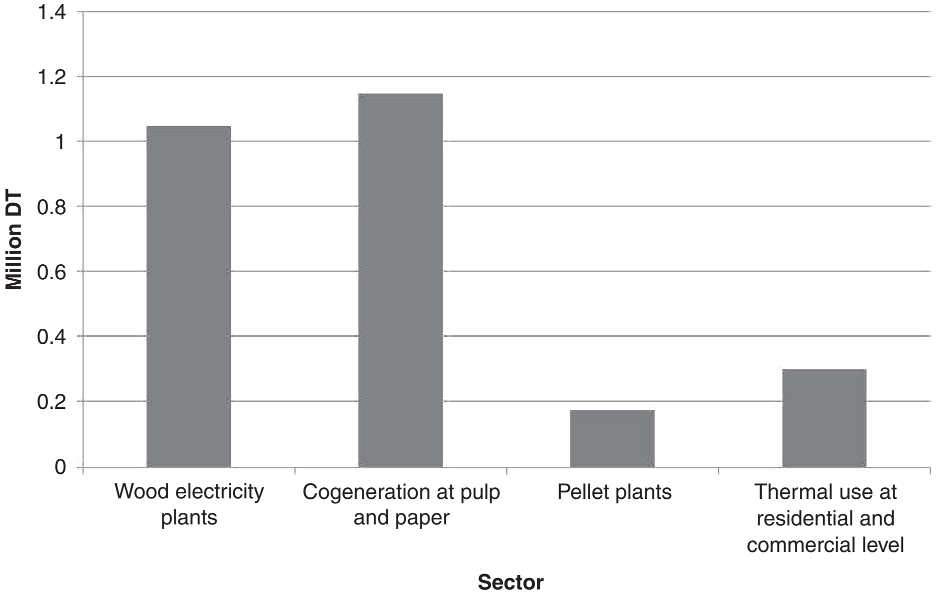

FIGURE 1 Annual wood use for energy by sector in Maine [(*26*), Figure 22, p. 14)].

to be generated; those credits are needed to make the fuel economically viable. Nothing stops biomass, other than ecological guidelines and regulations, from being used for non-RFS2-compliant biofuels or bioenergy (such as current market uses); it simply means that this makes them ineligible to generate an RIN credit that can be sold to an obligated party for regulatory compliance.

Under RFS2, it is unclear exactly how much of the potential biomass available in Maine and the Northeast would qualify as an acceptable source of renewable biomass. The RFS2 contains complex criteria, most of which indicate some level of active management.

Pursuant to 40 CFR 80.1401, renewable biomass from forests includes

> planted trees and tree residue from a tree plantation located on non-federal land (including land belonging to an Indian tribe . . .) that was cleared . . . at any time prior to . . . and actively managed on December 19, 2007.

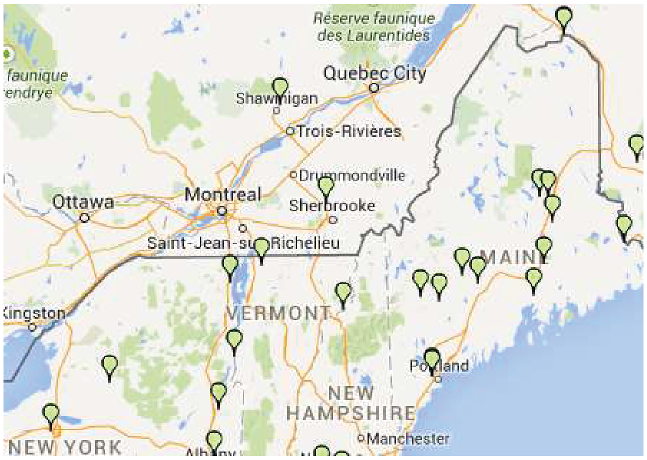

FIGURE 2 Pulp and paper mills in Maine and neighboring states (*28*).

Moreover, a tree plantations is

> a stand of no less than 1 acre composed primarily of trees established by hand- or machine-planting of a seed or sapling, or by coppice growth from the stump or root of a tree that was hand- or machine-planted. Tree plantations must have been cleared prior to December 19, 2007 and must have been actively managed on December 19, 2007 . . . and tree residue is slash and any woody residue generated during the processing of planted trees from tree plantations.

This portion of the definition suggests that forest plots that were planted are included as renewable biomass under this subpoint, but not forest plots that were naturally regenerated even if the primary purpose of the land is timber production for traditional uses of pulp, paper, saw logs, and energy generation.

In Maine, "partially harvested" (partial and shelterwood totals) accounts for about 95% of harvested acres; clearcutting accounts for less than 5%. A relatively small percentage of harvested land is extensively managed throughout the growth cycle. In 2012, herbicide was used on 1,105 acres for site preparation and on 9,507 acres to release crop trees from competing vegetation. Additionally, tree planting occurred on 7,417 acres of land (*31*). Modest additional amounts of land were also clearcut or had other types of more active forest management, but this compares with a total of 443,714 acres harvested in Maine in 2012, of which 418,675 were partially harvested (*27*). Since most of the timber harvested in Maine is not from planted trees or grown in a plantation setting, it is unclear how much of the excess forest harvest residue may qualify as renewable biomass under RFS2. In this case, then only a small percentage of Maine forestland may qualify as renewable biomass as defined.

However, the RFS2 renewable biomass definition also includes the following:

> (4) Slash and pre-commercial thinnings from non-federal forestland (including forestland belonging to an Indian tribe . . .) that is not ecologically sensitive forestland.
>
> (5) Biomass (organic matter that is available on a renewable or recurring basis) obtained from the immediate vicinity of buildings and other areas regularly occupied by people, or of public infrastructure, in an area at risk of wildfire.

Forestland is defined as "land that is at least 10% stocked by forest trees of any size, or land formerly having such tree cover, and is not currently developed for a non-forest use. The minimum area for classification as forest land is one acre." Additionally, slash is the residue, including treetops, branches, and bark, left on the ground after logging or accumulating because of a storm, fire, delimbing, or other similar disturbance.

This portion of the renewable biomass definition indicates that most of the tree tops and branches removed as a result of timber harvesting in Maine may qualify as renewable biomass under the RFS2 if the biomass qualifies as slash or as precommercial thinning, even if the forestland does not qualify as an actively managed tree plantation. Whole trees that could be used for pulp or other purposes, unmerchantable trees harvested through a clearcut, and any product harvested from an old growth forest, a late successional forest, or a forest with at risk ecology would not qualify as renewable biomass.

These different definitions in EISA appear arbitrarily to favor plantation forests over those that naturally regenerate. From an economic standpoint, it may not matter since, as will be argued, the economics of biomass harvesting favor integrated harvesting, with the primary purpose being the high-valued products for the pulp and paper and saw log industries.

Harvesting for Biomass in an Integrated Roundwood and Energy-Wood Whole Tree Harvest

A crucial question about biomass supply beyond its physical availability is the cost of harvesting the biomass and delivering it to a customer (plantgate). There are two potential ways to harvest biomass. One is biomass harvesting integrated with a conventional logging operation for saw logs or for pulpwood. The other is a harvest in which only biomass chips are produced, meaning that mature trees (trees that would typically be harvested for other uses in the current market), saplings, cull trees, or dead trees may be harvested and chipped; this may be done in a precommercial thinning to improve the quality of the stand. The integrated harvest approach is the most common, since biomass is a relatively low-value product.

Rather than being abstract, it is helpful to use a concrete example where some publicly available information exists. The Old Town Fuel and Fiber pulp mill (Old Town, Maine) applied for a Department of Energy waiver for a demonstration-scale integrated biorefinery (*32*). This plant uses between 900 and 1,000 DT per day (DTPD) of woodchips and a possible additional 169 DTPD operating as a biorefinery.

Biomass availability was estimated within the 50-mi radius of a proposed biorefinery in Old Town, Maine, by using FIA data. Using the same approach as described in the state level biomass availability estimation, absolute availability of limbs and tops, culls, and sapling biomass was estimated at the same proportion of their respective inventory. With the use of 33% and 45% biomass retention rates, biomass availability from tops and branches biomass was estimated to be 445,744 and 365,910 DT within the 50-mi radius around Old Town.

Within the specified radius, the individual harvest blocks have varying characteristics, such as species composition, number of trees per acre, diameter at breast height, tree volume, and distance to the end user. These harvest block characteristics affect both the delivered cost and the biomass supply. To estimate the amount of biomass under various harvesting and cost assumptions, biomass and cost at the forest stand level were estimated using the FIA database and modified fuel reduction cost simulator model applicable to Maine (*30*). This allows estimation of delivered biomass cost per unit harvested. The most important factors include the skidder bunch volume, price of diesel fuel, skidding distance, stumpage price, and trucking the chipped biomass to the plantgate. A 50-mi radius is used because this is the often-used benchmark for trucking in the industry. Calculations in this study show that trucking costs add from $2 to as much as $10 for a 100-mi round-trip trucking distance (*33*)

In Maine and elsewhere in the Northeast, most wood is transported to the end user by truck. However, in the Upper Peninsula of Michigan (with similar forests and end uses) as much as 22% is transported by rail in a bimodal rail and truck combination (*34*). In a bimodal delivery, woody biomass is transported by trucks from the landing to a rail siding, where it is then directly either transferred to rail cars, or temporarily stored before loading. Bimodal supply chains require at least one additional handling of the biomass, and that may increase costs unless offset by lower unit transportation expenses over longer distances. Abbas et al. found that bimodal shipping becomes less expensive than trucking in the Upper Peninsula for trips greater than 125 mi of total distance (road and rail) (*32*).

As described earlier, the amount of biomass from Maine forests that are RFS2-compliant is unclear. However, a conservative working assumption is that the limbs and tops of trees that are removed during an integrated roundwood whole-tree harvest operation do qualify. This assumption ignores saplings, salvageable dead trees, and culls. The portion of a tree made up of limbs and tops varies depending on the species and tree structure. As a result, studies have found a range for this value. Wharton et al. estimated that 23% of the total aboveground biomass belongs to limbs and tops (*11*), while Buchholz et al. estimated this value to be 19% (*19*). By using recent FIA data, it was found that this value was 27% on average.

Since biomass harvesting is a part of integrated harvesting operation, this amount is dependent on the size and feedstock demand of an existing pulp mill, percentage of biomass removed from the forest, and volume of total biomass composed of limbs and tops. Thus, actual limbs and tops biomass available for an existing pulp mill can be estimated with the following equation:

$$\text{mill DTPD} * \%\text{biomass removed} * \%\text{biomass limbs and tops}$$
$$= \text{RFS2 biomass}$$

Using 1,000 DT per day for mill operations and operating at 350 days a year implies an annual total woodchip requirement of 350,000 DT per day. Taking into account the upper-end biomass removal estimate of 0.67% based on the Maine governor's wood-to-energy task force report, and the current study's estimation of 27% limbs and tops contribution to the total above ground biomass, this yields 181 DT per day, or 63,350 DT per year, for an RFS2-compliant biomass to liquid fuel plant-based operating 350 days a year. However, this assumes that none of the biomass residues removed during the current pulpwood harvests are currently used, and that is unlikely to be the case. This will further reduce the availability of RFS2-compliant biomass.

$$1{,}000\ \text{DTPD} * 0.67(\text{biomass removed}) * 0.27(\text{limbs and tops})$$
$$= 181\ \text{DTPD}$$

Costs Based on Apportionment of Harvest Cost

As argued by Conrad et al. (*33*), Energy Information Administration (*35*), and Benjamin et al. (*36*), allocating only chipping costs to logging residues may not accurately reflect the true cost of harvesting the residues, given the opportunity cost of investing productive hours into logging residue harvesting and chipping, rather than in higher-value timber products. By using baseline delivered biomass cost with harvesting costs proportioned by volume of wood produced and nonstand specific assumptions, Whalley estimated that for Maine, the plantgate price is about \$28/GT or \$56/DT (*30*). Her sensitivity analysis showed that these delivered costs could range from \$7.16/GT to \$84.50/GT. Currently, biomass chips are being purchased for approximately \$25/GT (*36*).

Costs Based on Chipping-Only Harvest Cost

In contrast, the BTRU harvesting cost, assuming whole tree harvesting, treated harvest residue biomass as a waste product with a cost that included only chipping and stumpage. Using the same assumptions as before, Whalley estimated the delivered cost of biomass to be about \$10/GT or \$20/DT, with a sensitivity estimation ranging from \$3.88/GT to \$23.7/GT (*30*).

Harvesting for Biomass in a Stand-Alone Operation

Biomass harvesting by using conventional integrated methods is expensive compared with market prices. The maximum biomass supply limit can be estimated based on the higher-value timber products harvested and used in the area considered for a biorefinery. The understanding is that current RFS2 guidelines make harvesting for biomass in a stand-alone operation noncompliant for naturally regenerating forests. Nonetheless, these regulations could be revised by EPA, but that probably needs action from the U.S. Congress.

For the same 50-mi radius around Old Town Pulp mill, the total availability for non-RFS2-compliant biomass is 0.735 million DT. This includes limbs and tops (33% retention), cull trees (50% retention), and sapling biomass (85% retention). Using a 45% retention rate for limbs and tops, as recommended by Briedis et al. (*9*), the total availability becomes 0.65 million DT. However, these costs would be much higher, most likely equal to the cost of delivered pulp wood that currently markets for more than \$100/DT, or more than twice what is commonly thought to be economically viable for biofuel production. New harvesting methods, which decrease cost or a much higher delivered biomass price, would be needed to make stand-alone biomass chip production viable at a large scale (*8*). Absent this new technology, it is concluded that for biofuel production, only integrated harvesting is economically viable, and the estimate of biomass availability for biofuels should pay closer attention to the spatial location of existing large users of biomass, for remotely located stands will not be economically viable.

FINAL REMARKS

The continued national and international push for more liquid transportation fuels, particularly drop-in biofuels from cellulosic sources, poses a challenge for estimating resource availability taking into consideration both economic and ecological factors. The research shows that the literature has not come to a consensus on biomass availability. Moreover, the literature shows divergent methodologies and definitions of biomass—not even taking into consideration the real issues of how to adequately account for biomass retention needed for ecological sustainability.

The researchers' own estimate of the amount of biomass available for biofuel production in Maine is 3.9 million DT. This estimate should be understood in the context of the assumptions made with respect to biomass retention and the economics of harvesting that are dependent on other uses for wood in the pulp and paper and saw log industries. The perspective is that the economically viable production of biomass for biofuels makes sense only as part of an integrated harvest operation where the costs of harvest are shared. That means that a biofuel production facility in Maine and the Northeast that relies on naturally regenerating forests needs to be spatially located within about 50 to perhaps 70 mi (one way) of one or more other major users of wood. This requirement leads to a more narrow definition of economically available biomass that is often reported in the literature. The advantage of using this lower estimate of biomass, however, is that it is believed likely to be consistent with EPA regulations on renewable biomass that would qualify cellulosic biofuels produced from this wood source to contribute to national RFS2 fuel mandates. Simply, biofuel produced from the more limited feedstock supply is likely to be able to earn RIN credits that can help make the business case for cellulosic biofuels. EPA and the U.S. Congress could, of course, revise RFS2 to allow more naturally regenerating forests lands to qualify as renewable biomass.

ACKNOWLEDGMENTS

The authors thank Ken Laustsen and Jeff Benjamin for their assistance. This research received funding from the National Science Foundation Sustainable Energy Pathways, SEP Integrated National Framework for Cellulosic Drop-In Fuels.

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The Standing Committee on Alternative Transportation Fuels and Technologies peer-reviewed this paper.