Forest-based biomass supply curves for the U.S.

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Abstract. Nationwide county-level supply curves have been estimated for forest-based biomass in order to help evaluate their potential contributions to producing biofuels. This paper builds on the estimates of potential supply in the USDA/ DOE Billion Ton supply (BTS) study. Forest biomass sources include logging residue, thinnings, other removals, unused mill residue, urban wood waste and conventional sourced wood (pulpwood size material). To make the estimates it is assumed that lower cost forest biomass will be supplied from integrated harvesting operations which also remove sawlogs and pulpwood. It is assumed that such removals can be estimated at the county level in two steps. First as a portion of recent estimates of logging residues and second by simulated thinning operations that use tops, branches and small trees for biomass. Supply from thinning dense forest stands is assumed to occur over 30 years as in the original Billion Ton Supply Study. Harvest and stumpage costs are estimated for each of these methods. Final supply estimates for each county assume supply that is half way between the two estimates. Preliminary forest and agricultural biomass supply estimates have been used to indicate that for a marginal cost of $44 per oven dry ton (odt) at forest roadside or farm gate forest and agricultural feedstocks could produce 20 billion gallons of advanced biofuels as called for under the 2007 Energy Independence and Security Act. Forests could provide about 40 million odt of biomass per year at about $44 per odt to produce 4 billion gallons and agricultural feedstocks could provide about 200 million odt and produce 20 billion gallons of biofuel.

Introduction

In 2005 researchers from USDA and USDOE prepared estimates of potential biomass supply for bioenergy and biobased products from forest and agricultural sources (Perlack et al. 2005). That report suggested a potential supply of 1.3 billion dry tons of biomass per year. The estimates reported here build on the methods in that report and estimate biomass supply amounts and forest roadside costs[7] (supply curves) for each county in the U.S. The costs estimated are marginal costs or costs to supply each successively more expensive ton of wood biomass in each county. It is assumed that buyers would be facing landowners who are aware of the cost for the most expensive units of biomass supply in a county and that there would be enough buyers (competitive market) that landowners will only sell to buyers offering the price for the most expensive unit. Cost may be less for a given amount of biomass supply to the extent that landowners are not informed of about the highest price being offered, or are not interested in maximizing profit, or to the extent that there are few buyers to compete for the biomass.

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[7] Roadside cost is the price a buyer would pay for wood biomass chips at roadside in the forest, or, at a mill location in the case of mill residue, prior to any transport to the end use location.

This paper provides estimates of potential biomass supply for bioenergy for the U.S. from selected forest based sources. In this paper we use the term "biomass" to mean material that may be used for biopower or biofuels production, and, exclude – with one exception – wood sources that are currently used to make wood products. For some biomass sources we have estimates of county level supply curves and for other sources we currently have only preliminary national supply estimates with detailed county estimates to follow. The sources include 1) logging residue, 2) thinnings from timberland and other forest land, 3) wood from "other forest removals" such as land clearing and forest cultural operations, 4) wood and bark residue from primary wood products mills, 5) urban wood waste, and 6) conventionally sourced wood such pulpwood sized roundwood. These sources include kinds and amounts of wood that are not currently used for products such as logging residue and biomass from thinnings. They also include some sources that are already used extensively for products including mill residue and conventionally sourced wood (pulpwood).

We do not include estimates of pulp liquor from pulp and paper mill which is already used for production of heat and power nor do we include estimates of supply from short rotation woody crops that are being developed separately in conjunction with estimates for other agricultural sources. It is expected that woody crops will be grown on agricultural and pastureland and are thus are not considered part of the forestland resource base. We also do not include, in these initial estimates, potential amounts of wood from "other forest" land. "Other forest" includes a large area of Pinyon-Juniper forest in the West that could provide biomass but currently at a much higher cost than biomass from timberland – a current estimate is over $60 per oven dry ton (odt) at roadside (Western Governors Association 2008).

Methods

Because currently there are only limited markets to use forest biomass for biopower and biofuels, empirical data are not widely available on the amounts of biomass available for different costs – as there is for pulpwood or sawlog markets. In order to make estimates of biomass supply we generate cost estimates for several types of forest treatment and harvesting operations that can provide biomass. These treatment and harvesting operations must also consider sustainability constraints.

Estimates were developed for several sources by first identifying sustainability principles to guide their use. Specific guidelines are noted for each source discussed. In general terms, sustainability means today's management actions will not degrade the ecological functioning of a natural system[8] (Helms 1998). In the context of biomass removal from forests, the question of sustainability requires consideration of a wide range of issues, including: nutrient cycling and soil productivity, maintenance of biodiversity, water quality, and wildlife habitat. These factors, and resulting constraints on forest operations to address these concerns, are generally very site-specific. Soil productivity in certain soil types, for example, may be more sensitive to micro-nutrient levels and thus require retention of some level of woody residue. Wildlife habitat requirements may stipulate retention of snags or maintenance of coarse woody debris. Again,

[8] One detailed definition cited by Helms (1998) is "Sustainable forest management involves practicing a land stewardship ethic that integrates the reforestation, managing, growing, nurturing, and harvesting of trees for useful products, with the conservation of soil, air and water quality, wildlife and fish habitat, and aesthetics" from the UN Conference on Environment and Development, Rio De Janeiro, 1992.

ecological factors including wildlife and endangered species need careful site specific evaluations in determining biomass availability.

Sustainability is addressed in this analysis through several assumptions. The potential forest biomass supply that is modeled here is a secondary output of other management objectives. We consider biomass that would be available from forest health treatments, fire hazard reduction work, or treatment of activity fuels after logging where questions of sustainability are addressed in the larger management plan. The assessment also assumes ecological considerations and practical limitations would reduce the amount of biomass available for removal and utilization. The process used models of silvicultural treatments and estimates total available biomass (Shepperd 2007). The total available biomass is then further reduced to reflect material left on site to meet ecological constraints or is otherwise impractical to remove. We used reductions identical or similar to those in the "Billion ton supply" report (Perlack et al. 2005). The reduced amount is the net biomass available for removal. Although we apply these general restrictions we have not applied local restrictions such as the Northwest Forest Plan that may further modify our estimates.

In this paper we provide detailed methods and county level supply curves for biomass from 1) integrated harvesting operations that provide biomass as well as pulpwood and sawlogs, 2) other forest removals, and 3) wood and bark from mill residue. For urban wood waste and conventionally sourced wood we show national supply estimates.

For the first three sources of the six noted above, county level forest biomass supply curves are estimated for 1) non-federal forest land alone and 2) all forest land. The estimates are for forest biomass supply in the near term – for the next 5-10 years and presume a recovery of harvest in the forest sector to levels of production similar to those experienced in 2006-2007.

<u>Integrated harvesting operations – Thinnings and/ or logging residue from timberland</u>

It is assumed that a key source of lower cost biomass will be wood and bark taken from harvest sites where sawlogs and pulpwood are also taken in integrated harvesting operations. This removes wood fuels which would otherwise contribute to fire hazard. We assume integrated harvesting would take the form of removing whole trees to roadside where tops and branches are removed and chipped for biomass for fuel. Integrated operations would also remove small trees (less than 5 inches) to roadside where they could be chipped.

We envision that there are two separate steps to estimate the amount of biomass that may be provided by integrated harvesting and their roadside costs. After making separate estimates of county level supply curves using the two methods we combine them in a single estimate. We combine them by taking an average of the two supply curves (average of the two supply amounts at each supply cost). Essentially we are assuming that real world supply will be half way between the two estimates. For each of the two estimates we determine roadside costs and stumpage price for successively larger amounts of supply. Roadside costs include cost to harvest and move wood to roadside, and cost of chipping at roadside. These estimate were made using the FRCS model (Dykstra et al. 2009), Stumpage costs (cost per ton for biomass in standing trees) are estimated as an increasing fraction of pulpwood stumpage costs as amount supplied increases. We use pulpwood stumpage costs for 2007 as noted in Table 1. The first step to estimate county level supply curves is based on estimates of recent amounts of logging residue

that are generated and the second step is based on simulated silvicultural treatments on overstocked timberland that produce biomass, as well as pulpwood and sawlogs.

Logging residue based estimates - The first way we estimate biomass supply by county is to take a fraction of estimated logging residue left from recent harvesting operations as estimated in the USDA Forest Service Timber product output database for 2007 (USDA FS 2008). It is assumed that 65% of logging residue can be moved to roadside from private and public forest land. This is the same removal fraction assumed in the Billion Ton Supply report (Perlack et al. 2005). It is assumed that most of the logging residue is moved to roadside as part of whole trees and the only additional costs to supply the biomass will be for chipping at roadside and the cost for stumpage. Chipping costs, which vary by region and average about $13/ odt, were determined by the FRCS model (Dykstra et al. 2009, Fight et al. 2006).

The stumpage cost is assumed to be zero for logging residue biomass from federal land and range from $4/ odt to 90% of pulpwood stumpage price for private land and other public land. The stumpage price for logging residue from private land is assumed to increase from $4/odt when the first ton of logging residue is used up to 90% of pulpwood stumpage price (Table 1) when 100% of available logging residue used. The 100% level of available logging residue is estimated to be 65% of total logging residue generated as noted above.

Thinning simulation based estimates - The second way we estimate biomass supply by county for integrated operations is to simulate uneven-aged thinning operations on all timberland in the U.S. – as represented by Forest Service forest inventory (FIA) plots on timberland (Smith et al. 2004) – where stand density index is greater than 30% of maximum stand density index for the given forest type (Shepperd 2007). This simulates thinnings to reduce fire hazard and to improve forest health on overstocked stand. Uneven aged thinnings are simulated and estimates are made of the amounts of biomass, poletimber and sawtimber that are removed. For the West, biomass removals include 1) all wood from trees one to seven inches diameter breast-height (dbh) and 2) tops and branches of trees greater than seven inches dbh. For the North and South, biomass removals include 1) all wood from trees one to five inches dbh and 2) tops and branches of trees greater than five inches dbh.

It is assumed that all of the small-tree biomass can be extracted to roadside, but that only 80 percent of the volume in tops and branches of larger tress will make it to roadside due to breakage.

It is assumed that the only costs for tops and braches will be for chipping at roadside and the cost for stumpage. It is assumed that the cost to remove small trees will be the total cost for harvesting and hauling them to roadside as estimated by the FRCS model (which includes a cost for chipping) plus a cost for stumpage[9]. FRCS estimates the cost of providing biomass at roadside by whichever is the least expensive of three alternative harvesting systems—ground-based, whole-tree harvesting with mechanized felling; ground-based, whole-tree harvesting with manual felling; or cable yarding of whole trees that have been manually felled. Cable yarding is used only when the average ground slope exceeds 40 percent.

[9] The Biomass Treatment Evaluator (BTE) – a SAS program written by Patti Lebow – was used to prepare county level supply curves by 1) estimating biomass and industrial roundwood removals from thinning treatments on FIA plots on timberland, 2) assigning stumpage costs, and 3) assigning harvest and chipping costs using the FRCS model.

It is assumed that the simulated amounts of biomass supply will be harvested over a 30 year period. This is the same period assumed for thinnings estimates provided in the Billion Ton Biomass Supply report (Perlack et al. 2005).

Stumpage cost is assumed to be zero for biomass from federal land and $4/ odt to 90% of pulpwood stumpage price for private land. The stumpage price for private land is assumed to increase linearly from $4/odt for the first ton of biomass produced, to 90% of pulpwood stumpage price (Table 1) when the simulated removal of sawlogs plus pulpwood for a state reaches the year 2006 level of total sawlog plus pulpwood harvest. This state level restriction is to assure that the estimated biomass supply from integrated operations can be supported by the recent (year 2006) level of sawlog and pulpwood harvest in each state.

Table 1. Pulpwood stumpage prices and delivered prices by region, 2007

	Hardwoods	
	Delivered price	Stumpage price
	$/odt	
North	64.0	15.4
South	57.6	13.3
West		
	Softwoods	
	Delivered price	Stumpage price
	$/odt	
North	67.2	20.7
South	58.0	15.7
West	80.6	27.6

Sources: (RISI 2008) (FRCS model – Dykstra et al. 2009)

<u>Combining the logging residue and thinning based estimates</u> - It is assumed that as demand for biomass for biopower and biofuels increases, there will be a shift <u>from</u> integrated harvesting operations of a type and location that produce amounts similar to our logging residue estimates, <u>toward</u> integrated operations of the type and location represented by our thinning estimates. For our near term estimates we assume supply (for each county) will be represented by one half of the logging residue supply estimate and one half of the thinning supply estimate.

The possible error in our county level estimates of biomass supply from integrated harvesting could be substantial. Combining estimates from several counties around a point would reduce the error in estimating the supply for that specific location. Sources of error for a county supply amount from integrated harvesting at a given price include model specification error, error in logging residue amounts and fraction available, error in amount estimate based on few FIA plots, error in the future levels of harvest for pulpwood and sawlogs, error in harvest cost estimates and error in stumpage cost estimates.

Our model assumes – by using logging residue estimates, in part – that within 5 -10 years harvesting patterns will return to mid-2000 levels and will also shift to locations and treatment types simulated, broadly, by uneven-age thinning treatments. Actual levels and patterns will differ. Logging residue estimates have a possible error because they are based on surveys of

harvesting and studies of residue generated. Biomass estimates based on thinning simulation have possible error in that they use a limited number of plots to represent all possible treatments in a county.

One rough indicator of the possible error for thinning based estimates is the sampling error (67 percent confidence interval) associated with estimates of total standing forest biomass in given locality from FIA plot data. For example, we can estimate sampling error for total forest biomass in overstocked stands in selected local areas using FIA data. Within 10 miles of Athens, Georgia and Bend, Oregon there are FIA plots which estimate 154,000 and 134,000 odt in of total forest biomass in stands that are overstocked. The sampling error (67% confidence interval) for these estimates are 75% and 90%, respectively (USFS 2009). Our county level estimates of biomass supply are mostly under 50,000 for $50/ odt or less. Combining all sources of error for the thinning estimates it is plausible the standard error for county level biomass supply estimates may be 200% or 300% of the estimated value at a given price. If 10 equal county level thinning estimates are combined, each with a county sampling error of 250%, then the standard error of the total estimate would be 79% (assuming normal distributions for sample estimates). If this estimate were averaged with logging residue estimates (identical to the thinning estimates) from the 10 counties with standard error of 10% then the combined standard error would be about 40%. The 95% confidence level for the 10 county estimate would be about double the 40% level or 80%. So, actual biomass supply for multi-county areas could potentially be notably lower or higher than our estimates. This discussion is given only to suggest a rough order of magnitude for error in the estimates of biomass supply from integrated harvesting operations.

Wood from "other forest removals" such as land clearing and cultural operations

Amounts of other forest removals, by county, are obtained from the TPO database for 2007 (USDA FS 2008). It is assumed that 50% is available for use (Perlack et al. 2005). It is assumed that 34% of the amount available costs $20/ odt at roadside and the remainder costs $30/ odt at roadside.

Wood and bark residue from primary wood products mills

Amounts of wood and bark residue, by county, are obtained from the TPO database for 2007 (USDA FS 2008). For our initial supply estimates it is assumed that only unused mill residue is available. It is assumed the cost for unused residues is up to $10/ odt at mills. To be sure, mill residue currently used for low-value uses, such as mulch, could easily move to bioenergy applications in the range of prices considered here.

Urban wood waste

The amount of available urban wood waste is estimated to be about 28 million odt per year out of about 62 million tons generated per year (McKeever 2004). These estimates for 2002 are assumed to approximate the current level available. But it is assumed that only 10% of the amount available can be collected at a realistic cost. Cost at collection points is assumed to be $20 per odt.

Conventionally sourced wood – e.g pulpwood

Conventional products – pulpwood – could be used for bioenergy and biofuels if priced competitively with other end-use markets. An initial estimate of a minimum amount that could be supplied is the amount by which annual pulpwood harvest has declined over the last decade or so – about 15 million odt. If pulpwood stumpage prices are at least $13-$27 per odt as shown in

Table 1 and roadside chipping costs are $13 then even without covering any harvest costs the cost for pulpwood at roadside would be $26- $40 per odt. So it is plausible that relatively little pulpwood would be supplied for roadside costs less than $35-$50 per odt. As an initial estimate assume pulpwood supply will begin about $40 per odt at roadside and increase from there.

Results and Discussion

The forest based biomass supply curves for biomass from non-federal land prepared using the methods above are shown in Figure 1 and were used in combination with estimates of agricultural biomass supply curves to determine the mix and cost of forest and agricultural biomass supply that would be needed to meet cellulosic biofuels production targets under the 2007 Energy Independence and Security Act (EISA) (BRDi 2008). These targets call for production of 21 billion gallons of advanced biofuels (including cellulosic biofuels) by 2022. One scenario developed for that report indicates a 20 billion gallon target for advanced biofuels could be met by producing 4 billion gallons and 16 billion gallons from forest biomass and agricultural biomass, respectively. For about $44 per odt at forest roadside or farm gate we could make this biofuel from approximately 40 million and 200 million oven dry tons (odt) of forest biomass and agricultural biomass, respectively. The approximate 40 million odt of forestland supply excludes biomass from federal land to meet restrictions in EISA. The components of this forest based supply at $44 per odt are shown in Table 2 and total 43.8 million odt. Additional information on the kinds, amounts and costs of agricultural biomass identified to make 16 billion gallons of biofuels are in BRDI (2008).

For this analysis we have not provided detailed methods to estimate how much wood biomass supply may come from pulpwood size material at $44 per odt. We have conjectured that about 15 million odt. This supply would increase the total forestland biomass supply to nearly 59 million odt including all of the conventionally-sourced wood is included at $44 per odt. However the amount of pulpwood supplied could be larger if landowners price the costs for biomass (tops, branches, small trees) at nearer the roadside costs for pulpwood.

If forest supply could include biomass from federally-owned forestland then it is estimated that wood biomass supply would be least 4.4 million odt more (Table 2). The actual amount that would be taken from federal forestland would likely be more than 4.5 million odt given the total federal supply is likely to be somewhat less expensive. .

For several components of forestland-based resources, Table 2 indicates how much supply may be increased – within our sustainability constraints – if prices were to increase. For integrated supply using the forest thinning method we estimate supply could increase to 45.4 million odt per year if roadside prices were at least $100 per odt. This thinning supply is still constrained to provide no more than the 2006 level of pulpwood and sawlog harvest. For urban wood waste we conjecture supply at the source may increase from 10% of production (32 million odt) to 50% of production – 16 million odt. For conventionally-sourced wood – pulpwood – we estimated supply would at least increase by 15 million odt – an amount that would return production to its peak level in 1998.

It is important to note that the forest based biomass supply estimated here is in addition to amounts already supplied for residential wood burning and for electric power production. It is also important to note that – given the assumptions and methods used in this paper – if wood biomass demand were to reach 40 million odt for biofuels production and demand for wood

biomass for electric power production were to increase then these additional demands would increase use of pulpwood sized wood for biopower and biofuels. As stumpage prices being offered to use pulpwood for energy increase above recent levels (Table 1) total harvest would increase above recent levels of about 75 million odt per year (USFS 2008). With higher prices, the increment above 75 million odt would go for bioenergy and some of the amount below 75 million odt would shift from pulp and composites use to bioenergy use. As an illustration, if total use increases from 75 million odt to 100 million odt and there is a shift of 15 million odt from pulp and composite use to bioenergy use then total pulpwood use for bioenergy may be 40 million odt. More analysis is needed to evaluate how much pulpwood would be supplied as pulpwood stumpage price increases.

The amounts of biomass supply estimated here at $44 per odt are notably less than the maximum potential levels identified in the Billion Ton Supply (BTS) study. We estimate 35.7 million odt available from integrated harvesting – compared to 81 million odt in BTS. We estimate 8 million odt from other removals – compared to 9 million odt in BTS. We estimate no supply from other forest land at $44 per odt – compared to 11 million odt in BTS. We estimate 1.3 million odt from mill residue – compared to 8 million odt in BTS. We estimate 3.2 million odt from urban wood waste – compared to 28 million odt in BTS.

Supply of forest based biomass from the sources and amounts indicated in Table 2 – both the amounts provided at $44 per odt and the extended amounts would not notably alter the degree to which annual forest growth exceeds removals in the U.S. This is partly because of the common way forest growth and removals are measured. The common measurement is annual growth of growing stock – the growth in main stem of trees above 5 inches in diameter. Removals of growing stock – removals from the stock of standing trees – in 2006 were about 233 million odt tons (15.5 billion cf). The removals include amounts left on harvest sites as logging residue. In comparison net growth was 401 million odt (26.7 billion cf) (Smith et al. 2009). The amounts of supply noted in Table 2 would not increase removals of growing stock with the exception of conventionally-sourced wood. This is because they come from non growing stock parts of trees or from growing stock parts of trees that would previously have been left on harvest sites and would already be counted as part of the growing stock removals.

To provide a complete set of forest based biomass estimates detailed county level estimates are still needed for biomass from pulpwood sized roundwood and from mill residue that are currently used for fiber products (pulp and panels). Pulpwood supply for pulp and composite panel production was 74 million odt in 2006. Estimated mill residue used for fiber products was 35 million odt in 2006. As biomass price exceeds pulpwood price in a county, pulpwood going to bioenergy would include an amount from expanded harvesting and amounts of pulpwood and mill residue shifted from pulp and composite users to bioenergy users.

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Table 2 - Estimated forest based biomass supply for the United States with conventional harvest at 2006 levels

	Forestland resources excluding federally-owned land		All forestland resources		Increase when federal forestland is included	
Source	Estimated supply at $44 per odt at roadside	Extended supply	Estimated supply at $44 per odt at roadside	Extended supply	Estimated supply at $44 per odt at roadside	Extended supply
	Million od tons					
Integrated harvesting						
-Logging residue method x 0.5	20.0	20.0	22.0	22.0	2.0	2.0
-Thinning simulation method x 0.5	11.2	22.3	13.7	25.3	2.5	3.1
Total Integrated harvesting	31.3	42.3	35.7	45.4	4.5	3.1
Other removal residues	**8**	**12**	**8**	**12**	0.0	0.0
Primary mill residues (unused)	1.3	1.3	1.3	1.3	0.0	0.0
Urban wood residue	**3.2**	**16**	**3.2**	**16**	0.0	0.0
Conventionally sourced wood	**<5-15**	**15-40**[1]	**<5-15**	**15-40**[1]	0.0	0.0
Total	**43.8 – 58.8**	**71.6 – 111.6**	**48.2 – 63.2**	**74.7 – 114.7**	4.5	3.1

[1]The 40 million odt estimate for pulpwood supply is given as an example of possible level of supply if pulpwood prices increase notably. More analysis is needed to determine the pulpwood supply level as prices increase.

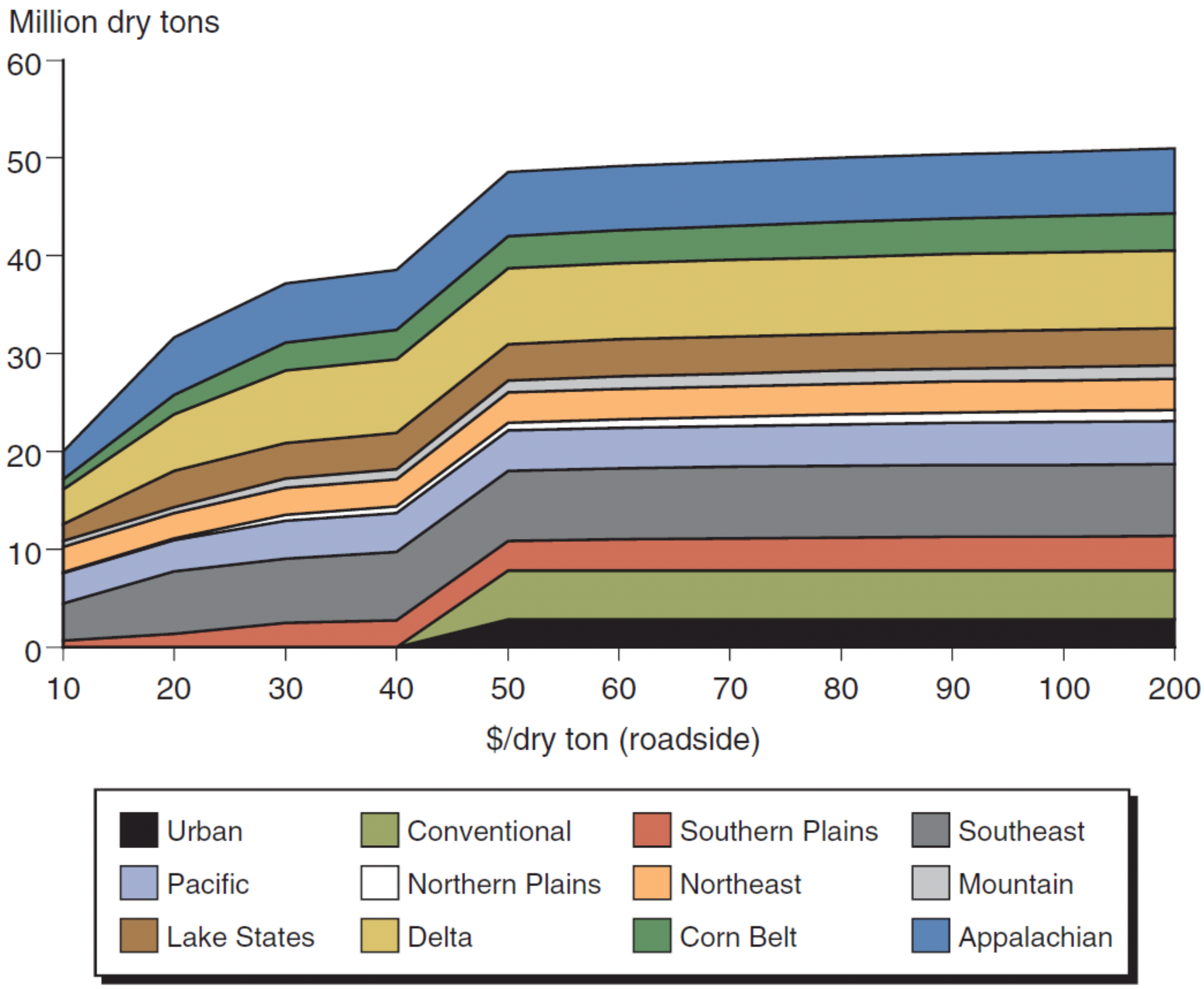

Figure 1 – Potential biomass supply from forests, mills residue, and urban wood waste

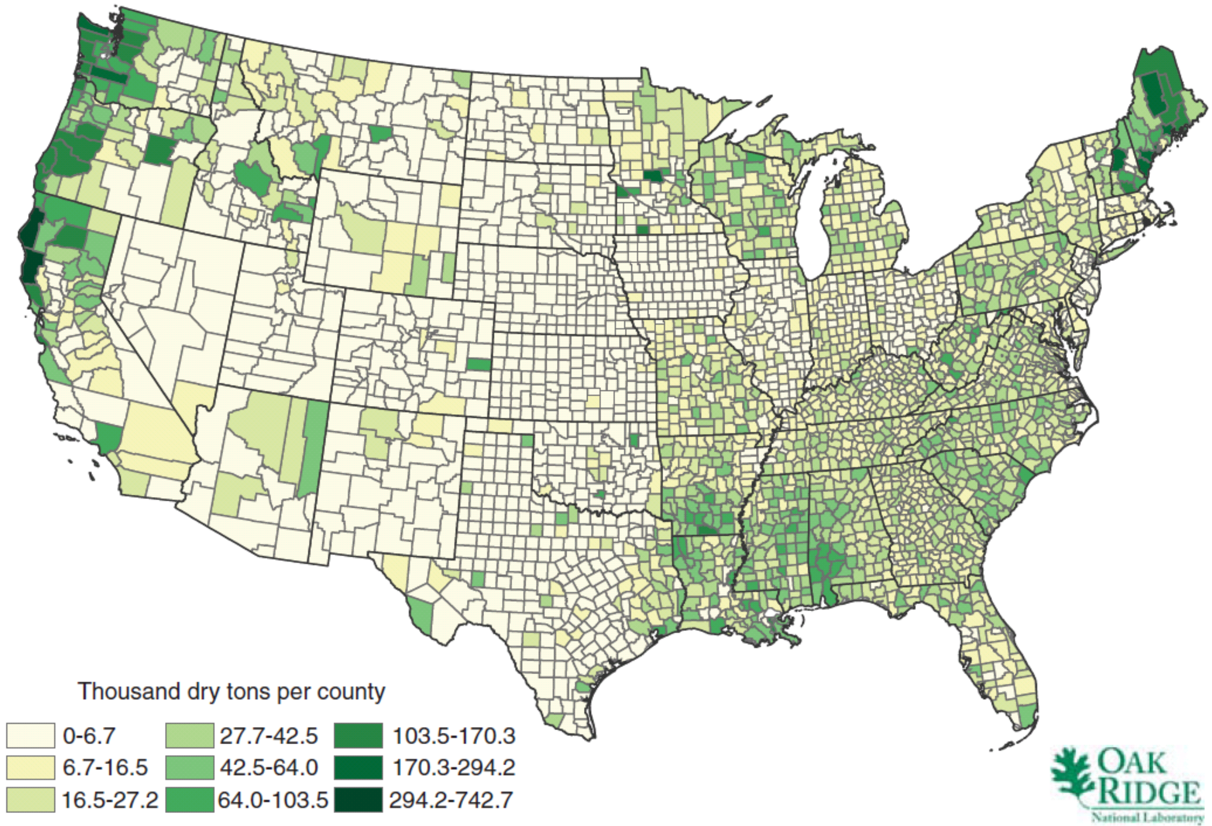

Figure 2 – Potential biomass supply from forests, mills residue, and urban wood waste, by county