



FOREST BIOMASS AND WOOD WASTE RESOURCES

This chapter provides estimates of forest biomass and wood waste quantities, as well as roadside costs (i.e., supply curves) for each county in the contiguous United States (see Text Box 3.1). Roadside price is the price a buyer pays for wood chips at a roadside in the forest, at a processing mill location in the case of mill residue, or at a landfill for urban wood wastes prior to any transport and preprocessing to the end-use location.¹⁴ Forest biomass and wood waste resources considered in this assessment include:

- Forest residues (logging residues and thinnings) from integrated forest operations from timberland¹⁵
- Other removal residue¹⁶
- Thinnings from other forestland
- Unused primary and secondary mill processing residues
- Urban wood wastes
- Conventionally sourced wood.

TEXT BOX 3.1 | FOREST FEEDSTOCKS

This chapter provides estimates for forest residues and wood wastes that were reported in the 2005 *BTS*, as well as an additional feedstock, conventionally sourced wood. In the original *BTS*, forest residues include logging residue, other removal residue, and fuel treatments from both timberland and other forestlands. Wood wastes include forest products wood residues (both used and unused), pulping liquors, and urban wood residues. The 2005 *BTS* also included fuelwood.

For this report, fuelwood, “used” wood wastes, and pulping liquors are included in the update, but are not counted as “potential” biomass resources because they are already used for other purposes, primarily energy production. Future prices may shift these “used feedstocks” into new or other energy uses, but for the update, they are still counted as used.

Fuel treatment residues are now “thinnings” obtained using an integrated forest operation, i.e., the production of merchantable products and biomass. A “composite” estimate is determined by combining portions of logging residue and thinning estimates, then by using a ratio to represent the transition from harvesting operations that leave logging residues to harvesting operations that integrate the removal of biomass with merchantable timber. Some conventionally sourced wood (e.g., small-diameter pulpwood) is also considered to be a biomass feedstock. See Chapter 1 for more discussion on the types of feedstocks.

¹⁴ The costs estimated are marginal costs or costs to supply each successively more expensive dry ton of biomass in each county. It is assumed that buyers would be buying from landowners who are aware of the cost for the most expensive units of biomass supply and that there would be enough buyers (a competitive market) such that landowners would only sell to buyers offering the price for the most expensive unit. Prices paid may be less for a given amount of biomass supply, depending on the extent that landowners are not informed 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.

¹⁵ Forestland is defined as land at least 120 feet wide and 1 acre in size, with at least 10% cover (or equivalent stocking) by live trees of any size, including land that formerly had such tree cover and that will be naturally or artificially regenerated (Smith et al., 2009). Forestland is further defined as timberland and other forestland. Timberland is defined as forestland that is producing, or is capable of producing, in excess of 20 cubic feet per acre per year of industrial wood and not withdrawn from timber utilization by statute or administrative regulation. Other forestland is defined as forestland other than timberland and productive reserved forestland. It includes available forestland, which is incapable of annually producing 20 cubic feet per acre per year. Reserved forestland is administratively removed from production.

¹⁶ Unutilized wood volume from cut, or otherwise killed, growing stock from cultural operations, such as precommercial thinnings or from timberland clearing. Does not include volume removed from inventory through reclassification of timber land to productive reserved forest land (Smith et al., 2009).

Forest biomass is a primary resource that consists of a combination of estimates from two sources: (1) removal of a portion of what is called logging residue that is currently generated during the harvesting of timberlands for conventional forest products and (2) removal of excess biomass from fuel treatment (reducing biomass helps forests increase fire resistance) and thinning operations designed to reduce risks and losses from catastrophic fires and improve forest health. This latter component consists of removing merchantable whole trees and excess small trees to the roadside. The tops and branches of merchantable trees, cull trees, cull-tree components, and excess small trees can be used for bioenergy applications. The merchantable tree components can be used for conventional forest products. Both of these resources were considered separately in the *BTS*, but in this update, estimates are made assuming that there will be a transition in conventional harvesting operations from leaving logging residues behind to removing them as part of conventional harvesting. It is projected that access to biomass will come from integrated harvesting operations that provide sawlogs and pulpwood to meet existing market demand, as well as provide biomass for energy. Two other primary resources are considered in this update. Thinnings from other forestland (non-timberland) are conducted to improve forest health by removing excess biomass on low-productivity land. Other removal residue is unused wood that is cut during the conversion of timberland to non-forest uses and unused wood cut in silvicultural operations, such as precommercial thinnings. A description of the forest resource land base is provided in Text Box 3.2.

The processing of sawlogs, pulpwood, and veneer logs into conventional forest products generates significant quantities of bark, mill residues (coarse and fine wood), and pulping liquors. With the exception of small quantities of mill residues, these secondary forest products industry residues are currently used in the manufacture of forest products or for heat and power production, and valuable chemicals are recovered from pulping liquors. In addition to pulping liquors, fuelwood—defined as wood harvested directly from forests and used primarily in the residential and

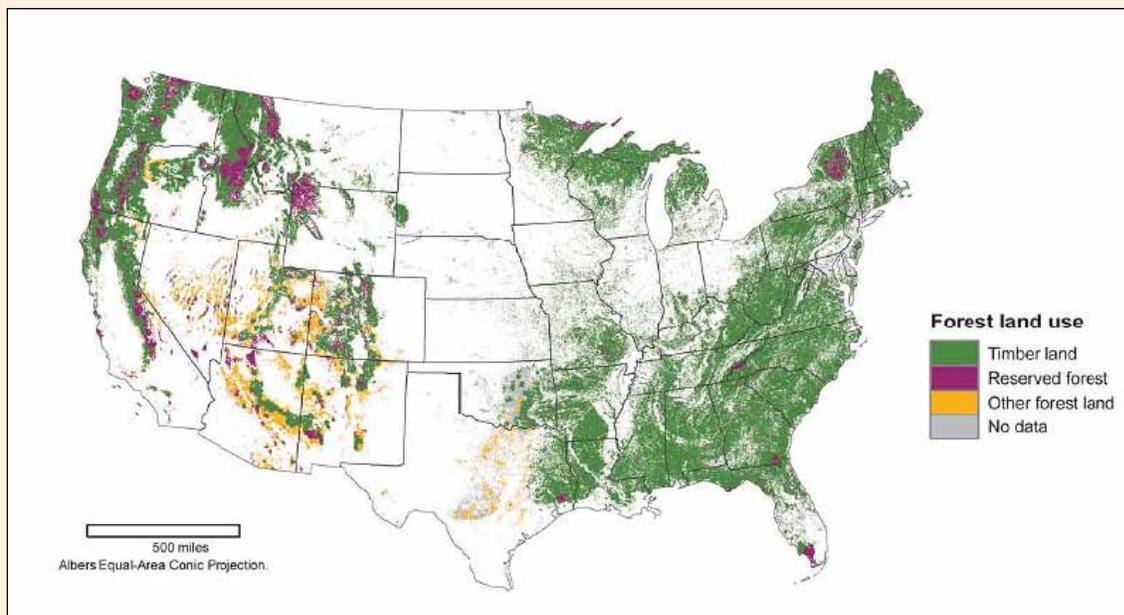
commercial sectors for space heating and by some electric utilities for power generation—is also not considered beyond the estimates provided in Chapter 1. Some quantity of these currently used wood wastes could shift to bioenergy applications at the right price. However, estimating how many of these resources could move into bioenergy production is difficult and speculative, as many of these wood wastes are not only used, but are also confined or dedicated to a specific process. Urban wood waste, on the other hand, is largely destined for landfills. The urban wood waste resource includes a wide variety of woody materials, ranging from discarded furniture, landscaping wood wastes, and wood used in the construction, remodeling, and demolition of buildings.

The final resource considered is conventionally sourced wood, which is defined as separate, additional operations to provide pulpwood-sized roundwood for bioenergy applications. Conventional wood was not included in the 2005 *BTS*. Excluded from the forest potential is wood grown under short rotations and dedicated to bioenergy production (see Chapter 5).

The remainder of this chapter discusses the specific woody biomass sources introduced above. The bulk of the chapter focuses on primary forest biomass, including extended discussion of resource sustainability from timberland. This is followed by other removals and thinnings on other forestland. Unused mill residues and urban wood wastes are discussed. The sixth section of the chapter provides estimates of how much conventionally sourced wood could be provided by additional harvest and by a shift of current pulpwood demand to bioenergy applications. The final section provides a summary of forest biomass and wood waste sources. All sections include key assumptions and data used to estimate applicable current and future supplies, as well as prices to access these resources. County-level supply curves are estimated for many of the resources; however, in this report, estimates are summarized by state and nationwide. A complete county-level database with projections of quantities and prices is available in a stand-alone database, the Bioenergy KDF (ORNL, 2010).

TEXT BOX 3.2 | FOREST RESOURCES OF THE UNITED STATES

In the United States, there are about 750 million acres of forestland, with slightly more than two-thirds classified as timberland or land capable of producing 20 cubic feet per acre annually of industrial wood products in natural stands (Smith et al., 2009). Another 22% of this forestland is classified as “other” and is generally not productive enough for commercial timber operations owing to poor soils, lack of moisture, high elevation, or rockiness. The remaining 10% of forestland is withdrawn from timber utilization by statute or administrative regulations and is dedicated to a variety of non-timber uses, such as parks and wilderness. The timberland fraction of U.S. forestlands totals approximately 514 million acres. As noted by Smith et al. (2009), the map below shows forested pixels from the USDA Forest Service map of Forest Type Groups (Ruefenacht et al., 2008). Timberland is derived and summarized from RPA plot data using a hexagon sampling array developed by EPA. Reserved land is derived from the Conservation Biology Institute, Protected Areas Database. Other forestland is non-timberland forests.



3.1 Primary Forest Biomass

Current removals from U.S. forestlands are about 21.2 billion cubic feet annually—nearly 320 million dry tons.¹⁷ This level of harvest is well below net annual forest growth and only a very small fraction of the total timberland inventory. In 2006, the ratio of forest-growing stock growth (wood volume increases) to growing stock removals (harvest, land clearing, etc.) in the United States was 1.71,¹⁸ which indicates that net forest growth exceeded removals by 71% (Smith

et al., 2009). The data also suggests a national trend of increasing net growth relative to growing stock removals. However, this trend varies by geographic region, species, and ownership, such as public forests and private industrial forests. In the case of private ownership (excluding Alaska) the growth to removals ratio is 1.3 as compared to a ratio of 5.3 for public lands.

¹⁷ These removals include roundwood products, logging residues, and other removals from growing stock and other sources. Removals refer to removal from standing timber inventory. Some roundwood (logging residue) is actually left on harvest sites. Volume is converted to dry tons using a factor of 30 dry pounds per cubic foot.

¹⁸ The growth to removals ratio is derived by dividing net annual growth of growing stock by annual removals of growing stock on timberland and excludes Alaska (Smith et al., 2009; Tables 34 and 35).

Slightly more than 70% of the volume of current U.S. wood removals is roundwood, with the remainder consisting of logging residues and other removals. Total logging residue and other removals in the United States currently amount to nearly 93 million dry tons annually—68 million dry tons of logging residue and 25 million dry tons of other removal residue (Smith et al., 2009).¹⁹ The logging residue material largely consists of tops, branches and limbs, salvageable dead trees, rough and rotten trees, non-commercial species, and small trees. Most of this residue is left onsite because its small piece size makes it unsuitable and uneconomic for the manufacturing of forest products. However, as markets for bioenergy feedstocks develop, a significant fraction of this residue could become economically feasible to remove, most likely in conjunction with conventional harvest operations where the costs of extraction (i.e., felling and skidding) are borne by the conventional forest product. [Forest biomass compliance with EISA is described in Text Box 3.3.] Other removal residue is wood cut, killed, or burned during the conversion of timberland to non-forest land uses (e.g., cropland, pasture, roads, and urban areas).

Trees killed and unutilized because of silvicultural operations, such as precommercial thinning of commercial forests, are also included in the removal residue category. This woody material is unutilized for reasons similar to the logging residue; it could become available for bioenergy production and other uses as technology, economics, and markets evolve. About 70% of the other removal residue is hardwood, attributable to the clearing of land in the North and Southeast where there is a preponderance of hardwoods.

In addition to forest residues generated by timber extraction and land-conversion activities, millions of acres (one estimate is at least 28 million acres in the West; USDA Forest Service, 2005) of forests are overstocked with relatively large amounts of excess biomass, which have accumulated as a result of forest growth and alterations in natural cycles through successful suppression of fires (USDA Forest Service,

¹⁹ The Forest Inventory and Analysis Program of the U.S. Forest Service conducts annual surveys and studies of industrial users to determine roundwood harvests for primary wood-using mills. Additional studies are also used to determine nonindustrial (i.e., residential and commercial) uses of roundwood. Taken together, these studies provide a comprehensive description of timber product output for a given year (USDA Forest Service, 2007a).

TEXT BOX 3.3 | FEEDSTOCK COMPLIANCE WITH EISA

The Energy Security Act (PL 96-295) of 1980 defines biomass as “any organic matter which is available on a renewable basis, including agricultural wastes and residues, wood and wood wastes and residues, animal wastes, municipal wastes, and aquatic plants” (U.S. Department of Energy, 2010c). This first-ever statutory definition became the standard for some legislative and programmatic purposes. Currently, 16 biomass definitions exist within recently enacted statutes and the Tax Code (Riedy and Stone, 2010). The 2008 Farm Bill Act and EISA definitions are typically regarded as the most comprehensive.

In the enactment of a new national Renewable Fuels Standard, as part of EISA, Title II, Sec. 201(I)(I), a more stringent definition was established that not only defines the types of feedstocks, but also defines the sources of the feedstock. In effect, EISA excludes all biofuels feedstocks from federal lands, except in narrowly defined areas at risk from wildfire.

For the purpose of this report, the original “organic matter” definition without additional statutory or regulatory definitional restrictions is used. This is because:

1. Subsequent laws, such as EISA, are for specific uses and final products—for EISA, it is biofuels. The *Billion-Ton Study* is an evaluation of availability without regard to final use.
2. There are other laws and pending legislation that would have to be included in a comprehensive analysis of available biomass “constrained by definition” that would detract from the goal of this report.
3. Restricting the analysis to definitional biomass availability reduces the usefulness of the information and conclusions if the definition changes.

Therefore, the availability of feedstocks from federal lands is analyzed and included separately. The results are shown by landownership for the convenience of the reader. Outputs are categorized as either public or private ownership. Public ownership includes federal, state, county, and city lands. Private ownership includes industrial and non-industrial lands.

2005; Graham et al., 2004).²⁰ As part of its Healthy Forest Initiative, the USDA Forest Service identified timberland and other forestland areas that have tree volumes in excess of prescribed or recommended stocking densities. The areas identified require some form of treatment or thinning to reduce the risks of uncharacteristically severe fires and are in close proximity to people and infrastructure. This excess biomass is classified as standing and downed trees in overstocked stands that would leave the forests healthier, more productive, and less susceptible to catastrophic fire hazard if removed.

An initial estimate of the potential supply of this fuel treatment wood was developed for five western states (USDA Forest Service, 2005). The study identified a large recoverable residue and merchantable wood resource ranging from a low of 576 million dry tons to a high of 2.1 billion dry tons that could be removed over a period of years. The low estimate included only 60% of the timberlands in the highest fire risk class and the same high estimate included all timberlands requiring some fuel treatment. About 30% of the total amount was considered residue—tops and limbs of large trees and saplings or trees too small for pulpwood or sawlogs, cull components of merchantable trees, and standing dead trees. [These operations are visualized in Figures 3.1 and 3.2.] A Web-based tool, the Fuel Treatment Evaluator, was subsequently developed to identify, evaluate, and prioritize fuel treatment opportunities that would remove excess biomass and promote a more natural fire regime pattern, with recurrence of less severe fire (Miles et al., 2006; Skog et al., 2006). This tool was used in the *BTS* to estimate the potential availability of fuel treatment biomass across the entire continental United States. The 2005 *BTS* provided an estimate of 60 million dry tons per year, with slightly more than 80% of the biomass on timberland and the remainder on other forestlands. The key assumptions behind this analysis included the exclusion of forest areas not accessible by road and all environmentally sensitive areas, equipment recovery

²⁰ In August 2000, the National Fire Plan was developed to help respond to severe forest fires and their impacts on local communities, while ensuring sufficient firefighting capacity for future fires. The National Fire Plan specifically addresses firefighting capabilities, forest rehabilitation, hazardous fuels reduction, community assistance, and accountability. The Healthy Forest Restoration Act (HFRA) of 2003 was then enacted to encourage the removal of hazardous fuels, encourage utilization of the material, and protect, restore, and enhance forest ecosystem components. HFRA is also intended to support research and development to overcome both technical and market barriers to greater utilization of this resource for bioenergy and other commercial uses from both public and private lands. Removing excess woody material has the potential to make relatively large volumes of forest residues and small-diameter trees available for bioenergy and biobased product uses.

Figure 3.1 : Forest residue operation in northern California



(Courtesy of Han-Sup Han, Humboldt State University)

Figure 3.2 : Removal of forest biomass with a skidder



(Courtesy of Han-Sup Han, Humboldt State University)

limitations, and merchandizing thinnings into two utilization groups (conventional forest products and bioenergy products).

Although the demand for roundwood, as well as the extent of land-clearing operations, ultimately

determines the amount of forest residue generated, environmental and economic considerations set the amount that can be sustainably removed. The next section of this chapter discusses forest resource

sustainability and is followed by a discussion of the methods and data used to estimate county-level quantities and prices for the major forest residue feedstocks.

3.1.1 Sustainability of Extracting Primary Forest Residue Biomass

While the sustainability of harvesting traditionally merchantable roundwood has been studied at great length, the additional harvest of logging residues and small-diameter trees for bioenergy creates new concerns over forest ecosystem sustainability (Janowiak and Webster, 2010). Biomass feedstocks may be harvested from a wide variety of forest management systems, ranging from extensively managed, naturally regenerated forests to short-rotation woody crops (SRWC). Each forest system has its own issues with respect to sustainability. While these issues must be addressed, the sustainable extraction of forest residues can be achieved through either the application of best management practices (BMPs)—that are voluntary or statutory (regulated by states)—or through formal forest certification programs (BRDI, 2008). In all cases, these practices are science based and have the goals of protecting ecological functions and minimizing negative environmental impacts. In the case of fuel treatment operations, biomass harvesting will enhance forest health and vitality as long as some stand structure is left to provide continuous cover, erosion control, and habitat (Figure 3.3) (Graham et al., 2004).

Within the most intensive woody biomass feedstock systems, maintaining site productivity is imperative to efficient management. Nutrient deficiencies that may be present are mitigated as a matter of course through fertilization. The management of these systems in terms of the intensity of soil disturbance; technological inputs to manage water, nutrients, and non-crop vegetation; and harvest intensity, is more intensive than traditional forestry, but usually less intensive than typical agricultural systems. Blanco-Canqui (2010) reviewed the sustainability of these systems in comparison to other agronomic biomass feedstock systems and notes that, in comparison to annual systems, short-rotation woody crops offer several environmental advantages. When sited on

marginal agricultural land, these systems improve soil productivity and offer additional environmental benefits, such as improved water quality and wildlife habitat.

Within conventionally managed forest ecosystems, concerns over biomass harvesting involve both operational concerns associated with harvesting and thinning operations, as well as the ecological concerns over the removal of additional wood following conventional stem-only harvests (Page-Dumroese et al., 2010). Some dead woody biomass is left onsite, as it serves several important ecological functions in forest ecosystems (see comprehensive review by Harmon et al., 1986) that are affected by harvesting. Dead woody material serves as a habitat for a variety of organisms, including fungi, mosses, liverworts, insects, amphibians, reptiles, small mammals, birds, and regenerating plants. In cool climates, downed logs act as nurse logs for seed germination and stand establishment. Birds forage, nest, and hunt in and on dead wood. Dead woody material affects ponding, sediment trapping, and aeration in streams; it also impacts site productivity through several mechanisms.

Figure 3.3 Sustainable harvest from managed forest systems



(Courtesy of Evergreen Magazine)

This dead biomass alters site water balance and water quality through storage and release of water and by reducing runoff and erosion. It is commonly used during harvest operations to protect wet soil areas from compaction and rutting, and it is used post-harvest to help limit runoff and erosion from skid trails and forest roads. Finally, dead woody material supports biological nitrogen fixation, thereby increasing onsite levels of nitrogen, and it contains nutrients that are cycled back into the soil.

The loss of nutrient capital and organic matter due to biomass harvesting is of particular concern to sustaining site productivity and carbon sequestration potential. While biomass harvesting includes more sources than just harvest residue from conventional harvest systems, the majority of research in the United States on nutrient removals from biomass harvesting has focused on the impact of whole-tree harvesting relative to conventional harvesting and the removal of small-diameter trees for silvicultural and fire protection purposes. Whole-tree harvest is usually defined as all woody biomass contained in standing trees above ground, where complete-tree harvest removes the stump and large root biomass, as well. More intensive biomass harvesting involves removing existing dead wood from the site. Logging residues, or the remainder of the standing tree after the conventionally merchantable bole is removed, contain a disproportionately high nutrient content relative to the bole. For example, a whole-tree harvesting study of six hardwood and five conifer stands showed the removal of about 23% more biomass than stem-only harvesting, but 49%, 40%, 38%, and 36% more nitrogen, phosphorus, potassium, and calcium (Mann et al., 1988). Similarly, whole-tree harvesting removes about 16% more biomass from Douglas-fir stands, but 65%, 83%, 52%, and 169% more nitrogen, phosphorus, potassium, and calcium (Mann et al., 1988). Small-diameter trees removed in thinning operations or in dedicated short-rotation woody crop systems also have a comparatively high nutrient capital due to higher proportion of high nutrient-concentration biomass (leaves or needles, branches, and bark). Thus, the nutrient removal is much greater in biomass harvesting systems than in conventional harvesting systems relative to the actual amount of biomass

harvested. Therefore, it is important to manage the retention of portions of the biomass to ensure long-term productivity through leaving residues or time of harvest. ensure long-term productivity through leaving residues or time of harvest.

However, few long-term studies have followed the growth response of the next rotation following harvest to determine whether site productivity was affected. Johnson and others (2002) found that whole-tree harvesting had no effect on the 16-year growth of an oak-hickory forest compared to stem-only harvesting. Whole-tree harvesting did reduce the 16-year growth of a loblolly pine plantation in South Carolina, which was attributed to the loss of nitrogen and to physical property differences in soil; in stem-only harvested plots, the woody debris significantly improved physical attributes of soil (Johnson et al., 2002). Powers et al. (2005) summarized the findings from 26 installations of the USDA Forest Service Long-Term Soil Productivity (LTSP) study and found that complete aboveground organic matter harvest (including the forest floor) reduced the 10-year growth in aspen stands compared to bole-only harvest, but had no consistent effect for mixed conifers in California and Idaho or southern pine in Louisiana, Mississippi, and North Carolina. Scott and Dean (2006) showed that 7- to 10-year growth of loblolly pine was reduced by an average of 18% on 15 of 19 research blocks across six separate research studies in the Gulf Coastal Plain. Soil carbon sequestration is also rarely reduced substantially by biomass harvesting (Johnson and Curtis, 2001). These scattered results indicate that, in general, intensive harvesting does not universally reduce site productivity, but in some cases, it can cause substantial growth declines if not mitigated. Further research is ongoing at the more than 100 installations of the LTSP study (Powers et al., 2005), and as this study evolves, more information will be available for long-term growth responses and soil carbon sequestration across a variety of forest types and sites.

As noted by the few reports of long-term growth, intensive biomass removals will have no discernible effect across many sites. Numerous sites are well buffered with respect to nutrients, so that even repeated intensive removals over long periods may not induce nutrient deficiencies. Sites with low slope and little

susceptibility to compaction do not require much biomass to mitigate erosion and compaction concerns. However, there are some regional-, soil-, and forest-specific origins. Some forests in the eastern United States are at a relatively high risk of calcium loss from harvest (Huntington, 2000). The loss is due to low-calcium geologic parent materials, decades of acid precipitation that have leached much of the natural calcium capital from the soil, and (in the southeastern United States) the high degree of weathering. In southeastern pine forests, certain geologies are markedly low in phosphorus and routinely fertilized to overcome their natural deficiency and to avoid induced deficiency by harvest removals. Nitrogen is a limiting factor throughout the United States, with the exception of the Northeast. However, in dry or cold forests where nitrogen cycling is retarded due to climate, nitrogen losses in harvested materials may substantially reduce productivity by lowering decomposition and nitrogen mineralization rates. Continued research is needed to identify specific forest and soil types where biomass removal may exacerbate potential deficiencies, and mitigation strategies will need to be developed.

Fertilization is a common treatment that is used primarily to increase forest growth, but can also be used to mitigate nutrient removals from biomass harvesting. Application rates for important commercial species (e.g., loblolly pine and Douglas-fir) commonly range from 22–54 pounds per acre of phosphorus and 180–224 pounds per acre of nitrogen. Wood ash, created during wood combustion for energy, can be safely used to replace calcium and other basic cations removed through biomass harvesting (Pitman, 2006). Concerns related to the impact of forest fertilization on water quality have generally been unfounded (Binkley et al., 1999), even in intensively managed systems (McBroom et al., 2008) or when biosolids are applied (Pratt and Fox, 2009).

Based on the ecological- and productivity-related roles of dead woody debris and the fact that some timberland owners may not want to—or be able to—fertilize, in order to mitigate potential productivity loss, some level of woody material should be retained to protect these functions. Some of the material may be present in a stand prior to harvest, while some is created as logging residue or by density-induced natural mortality.

Because dead wood is important in many complex functions, and the amount needed to perform these functions varies widely across climatic, geologic, edaphic, and vegetation gradients, a single retention percentage should not be used as an actual guideline. Rather, retention guidelines should be developed at state-to-local geographic scales, by forest type, and by harvesting intensity. Several states and the two largest certification programs in the United States (Sustainable Forestry Initiative® and Forest Stewardship Council) have released guidelines that address the productivity and ecological functions of dead wood (Evans and Perschel, 2009). Most of the guidelines were developed for general timberland conditions, with some additional restrictions for special areas, such as critical plant or animal habitat, shallow soils, or steep slopes. For example, Maine requires all coarse woody material that exists prior to harvest to be retained after harvest, and at least 20% of the logging residues with less than 3-inch diameters should be retained. Minnesota recommends that 20% of the logging residues be retained and scattered throughout the harvest tract. Wisconsin's guidelines require 5 tons per acre of woody material to be retained, but the material can be derived from either logging slash or woody material present prior to harvest. Pennsylvania's guidelines call for 15% to 30% of the harvestable biomass to be retained, while Missouri calls for 33% retention. Sensitive sites and soils are also protected. Minnesota suggests avoiding biomass harvesting in areas with threatened, endangered, or otherwise sensitive plant or animal habitats from within riparian management zones, on certain organic soils, and on shallow soils with aspen or hardwood cover types. In general, the literature and harvest guidelines indicate that retaining 30% of logging residues on slopes less than 30% and 50% retention on steeper slopes is a reasonable and conservative estimate of the amount of material needed to maintain productivity, biodiversity, carbon sequestration, and prevent erosion and compaction.

For the United States, Janowiak and Webster (2010) offer a set of guiding principles for ensuring the sustainability of harvesting biomass for energy applications. These principles include increasing the extent of forest cover, including the afforestation of agricultural, abandoned, and degraded lands, as

well as the establishment of plantations and short-rotation woody crops; adapting forest management to site conditions by balancing the benefits of biomass collection against ecological services provided (e.g., old-growth forests provide ecological services and habitat benefits that greatly exceed bioenergy benefits); using BMPs; retaining a portion of organic matter for soil productivity and deadwood for biodiversity; considering forest fertilization and wood ash recycling; and, where appropriate, using biomass collection as a tool for ecosystem restoration. When these

principles are applied through state-based BMPs or biomass harvesting guidelines or certification, biomass harvesting can be sustainably practiced with reduced negative impacts on the environment, and harvesting can be a much-needed tool for achieving forest health restoration objectives.

A summary of the operational sustainability criteria used to estimate primary residue supply curves is provided in Table 3.1.

Table 3.1 Summary of Sustainability Assumptions Used in Developing Forest Residue Estimates

Forest biomass resource	Environmental sustainability	Economic/technical
Logging residues, thinnings, and conventionally sourced wood.	<p>Administratively reserved forestlands excluded. These are lands excluded from timber production by legislative statute and include wilderness and National Parks.</p> <p>Inventoried roadless areas are excluded. These are USDA Forest Service lands identified as possibly qualifying for wilderness or other conservation protections.</p>	<p>Logging residues result from conventional harvests; therefore, assume that there is road access to the biomass and no road building is required.</p> <p>For the thinnings and conventionally sourced wood only, the FIA variable “distance to road” was used to determine road access. If over 0.5 miles, then the high cost excluded biomass because of lack of current road access.</p>
Logging residues from after commercial timber harvesting.	<p>Thirty percent of logging residue is left onsite for sustainability reasons. These residues include non-merchantable trees and tree components, as well as standing and dying trees.</p>	<p>Prices to roadside are assumed to be stumpage price plus chipping (no stumpage cost on federal land). Estimated prices were used to develop supply curves.</p>
Integrated harvesting to produce commercial products and biomass from timberlands and other forestlands.	<p>Estimated biomass amounts are from simulated uneven-age treatments on overstocked stands where treatments are assumed to occur on a 30-year cycle</p> <p>Retention was determined as a function of slope: Slope is less than 40%, then 30% of residue is left onsite Slope is greater than 40% to less than 80%, then 40% of the residue left onsite Slope is greater than 80%, then no residue is removed (no limbs or tops yarded)</p>	<p>Restricted to sites where stand density index is greater than 30% of maximum by forest type</p> <p>Cable yarding sites (slope greater than 40%) are assumed inoperable if yarding distance exceeds 1300 feet</p> <p>Uneven-age management is practiced (selected trees are removed from all diameter classes)</p> <p>Biomass supply is from removal of (1) trees 1 to 5 inches in diameter at breast height (dbh) in the East and 1 to 7 inches dbh in the West and (2) tops and branches of larger trees</p> <p>Whole tree harvesting is assumed (trees are taken to roadside for processing)</p> <p>Costs to provide biomass from tops and branches include only stumpage and chipping (no stumpage cost on federal land)</p> <p>Prices to provide biomass from whole trees include costs for stumpage, harvest, and chipping (no stumpage on federal land)</p>

3.1.2 Logging Residues and Thinnings

There are two major sources of residues from forest stands: (1) the limbs, tops, cull trees and cull tree components, and downed trees from harvesting operations (logging residues), and (2) the non-merchantable components of stands that are thinned as part of fuel treatments and restoration harvests (thinnings). These two forest biomass resources only come from non-reserve forestland, which is land that is not removed administratively or designated as roadless²¹ (Table 3.1). These non-excluded resources either have existing roads, as in the case of logging residues, or they could be accessed from existing roads at an acceptable price. The largest source of some of the lowest-cost forest feedstocks is biomass removed along with sawlogs and pulpwood in integrated harvesting operations. This removes fuel that can contribute to fire risks. Integrated harvesting operations are assumed to take the form of removing whole trees to roadside, where tops and branches are removed and chipped for bioenergy feedstock (Figure 3.4). Integrated operations would also remove small trees (less than 5 inches in diameter at breast height (dbh) in the East and 7 inches dbh in the West) to the roadside where they are also comminuted (Figure 3.4). In integrated operations, there is a certain fraction of logging residues left on the site intentionally for retention purposes (see Table 3.1). A minimum of 30% biomass was assumed to be retained on the site, and even more was assumed for steeper slopes.

Two separate methods—recovering logging residues behind conventional harvesting operations and simulated forest thinning with integrated harvesting operations—are used to estimate the quantity and roadside price of the available biomass (see Text Box 3.4). After making separate estimates of county-level supply curves using these two methods, they are combined into a single, composite estimate for a county. This can be done by taking an average of the two supply curves (average of the two supply amounts at each supply price) or a percentage of each, such as 50% logging residue and 50% forest thinnings, which is used in this analysis.

For each of the two estimates, roadside costs and stumpage²² prices are determined for increasing incremental amounts of supply. Roadside costs include the cost to cut and extract wood to roadside and the cost of chipping at roadside. These estimates were made using the Fuel Reduction Cost Simulator (FRCS) model (Dykstra et al., 2009). Stumpage prices (cost per ton for biomass in standing trees) are estimated as an increasing fraction of baseline pulpwood stumpage prices as the amount supplied increases. Regional pulpwood stumpage prices for 2007 are summarized in Table 3.2. 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 estimates. Logging residue estimates are available from the Timber Product Output (TPO) database (USDA Forest Service, 2007a). The TPO consists of a number of data variables that provide timber product harvested, logging residues, other removal residues, and wood and bark residues generated by primary forest product processing

Figure 3.4 : Comminuting forest residue bundles



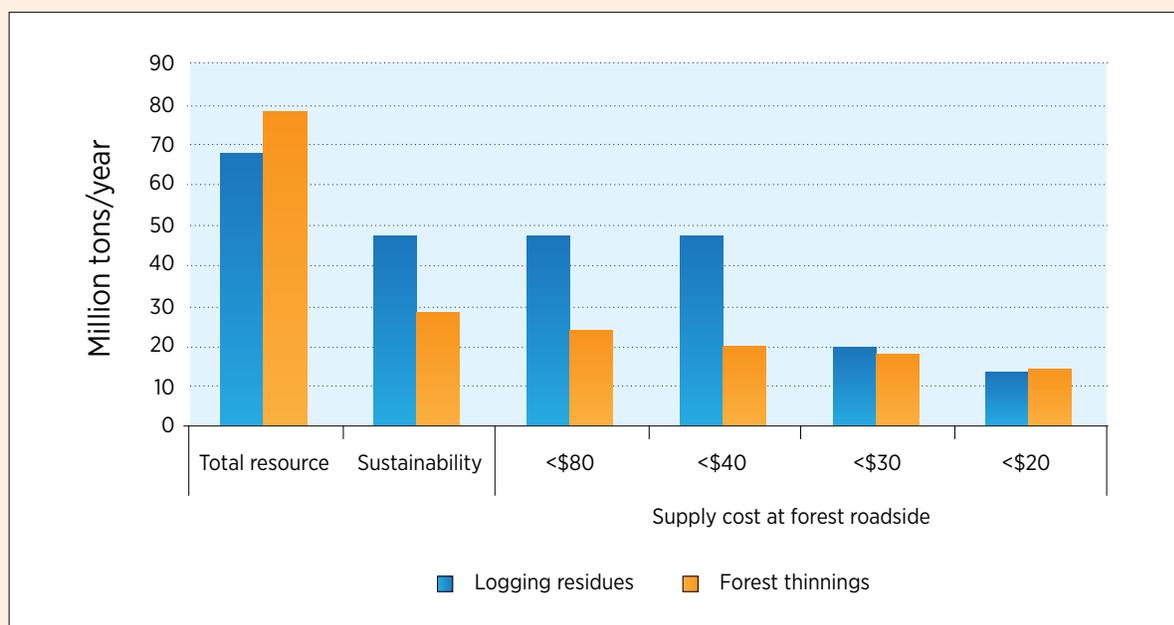
(Courtesy of Han-Sup Han, Humboldt State University)

²¹Roadless areas are defined as lands without constructed roads and have been delineated by government review.

²²By definition, stumpage is the value of standing trees (i.e., standing on the stump) uncut in the woods.

TEXT BOX 3.4 | LOGGING RESIDUES AND THINNING ESTIMATES

The logging residue-based and simulated forest thinning-based estimates before sustainability and cost restrictions are shown below. Slightly more than 60% of these sources can be harvested once requirements for ensuring sustainability are met. All of the logging residue resources can be harvested at less than \$40 per dry ton roadside and more than 90% can be harvested at less than \$30 per dry ton roadside. At less than \$40 per dry ton roadside, about 70% of the thinnings can be harvested. The higher costs for thinnings generally reflect the presence of small-diameter trees, which incur harvesting and skidding costs in addition to stumpage and chipping.



mills for each county. The TPO Tablemaker, a U.S. Forest Service online tool, was used to access the TPO data. [The Tablemaker is no longer available and has been replaced with other programs (U.S. Forest Service, 2011a).] The TPO database combines forest industry and other private ownership classes into an undifferentiated private class to comply with the Privacy Law. The undifferentiated private class was used in this analysis and will be available on the KDF. The logging residues are estimated using harvest utilization studies and represent the total volume left on the site. It is not economically feasible to actually recover all of the biomass, and due to sustainability reasons, at least 30% of the biomass is left onsite. Therefore, the estimated biomass was reduced by sustainability percentages shown in Table 3.1. Using these reduction factors and cost curves, no further reductions were needed because of economic feasibility, which means that a recoverable factor

was not needed as used in the *BTS* (Perlack et al., 2005). The non-recoverable fraction left onsite, which includes leaves, branches, and parts of the tree crown mass, provides nutrients and serves to maintain soil productivity.

An assumption in this analysis is that most logging residue is moved to roadside as part of a whole-tree harvest of merchantable wood, and the only costs will be for stumpage and chipping at roadside. In cases where cut-to-length systems are used, which means that residue is left in the stand where the trees are processed, the assumption is that the biomass will not be recovered (Figure 3.5) (see more complete explanation in thinning section). Chipping costs were determined by the FRCS model (Fight et al., 2006) as modified and expanded to cover the U.S. North and South, as well as the West, by Dykstra and others (2009). Prices average about \$13 per dry

ton nationwide and are slightly higher in the West and slightly lower in the South due to differences in labor and fuel costs. Stumpage price is assumed to be zero for biomass from federal land because biomass removal is usually part of a fuels treatment or restoration activity. For privately owned timberland, stumpage price is assumed to begin at \$4 per dry ton and increase to 90% of the pulpwood stumpage price when 100% of the available logging residue is used. The low entry price is based on a token payment in the likelihood that the biomass is only removed to meet other landowner objectives, such as reducing site preparation costs or fire risks. The higher prices are the result of demand increasing or supply decreasing to the point that biomass is almost competitive with pulpwood.

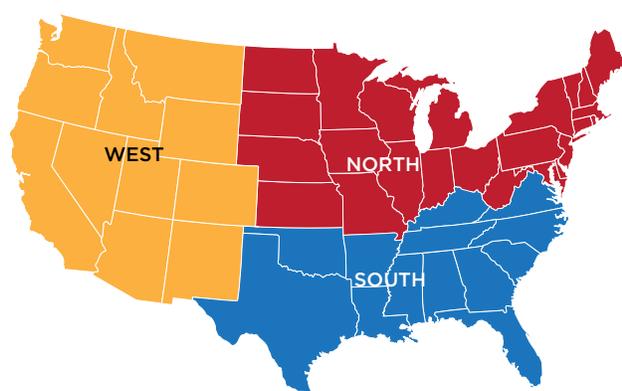


Table 3.2 Pulpwood Stumpage Prices by Region

	Delivered price (\$/green ton)	Stumpage price (\$/green ton)	Stumpage price (\$/dry ton)
Hardwoods			
North	\$32.00	\$7.70	\$15.40
South	\$28.80	\$6.70	\$13.30
Softwoods			
North	\$33.60	\$10.40	\$20.70
South	\$29.00	\$7.80	\$15.70
West	\$40.30	\$13.80	\$27.60

Source: RISI, 2008; Fight et al., 2006; Dykstra et al., 2009
(Includes all types of ownerships)

The supply curve based on logging residue estimates is shown in Figure 3.6 (thinning and composite supply curves shown in Figure 3.6 are discussed in subsequent sections). The logging residue supply curve is generally flat and shows 47 million dry tons per year potentially available at a roadside price of \$40 per dry ton or less from all defined forestlands (Table 3.3 in Section 3.7). There is a 9% decrease in available tons per year generally across all prices when the federal lands are removed per EISA definitions. All logging residues are available at this price. State supplies at \$80 per dry ton per year are graphically summarized in Figure 3.7. The largest supplies are where pulpwood and sawlog harvests are the greatest, namely the Southeast, Northwest, and Great Lakes. A more spatially explicit summary of logging residues supplies at \$20 and \$40 per dry ton is shown on the maps in Figure 3.8. Table 3.4 shows that at \$60 per dry ton in 2030, about 50 million dry tons are available. These estimates are derived using USDA Forest Service Resource Planning Act (RPA) projections of timber harvests from forestland by region and estimates of logging residue as a percentage of timber product removals (Haynes et al., 2007).

Figure 3.5 Logging residues



(Courtesy of Barry Wynsma, USDA Forest Service)

Figure 3.6 National supply curves for logging residues, thinnings, and composite (50% logging residues and 50% thinnings) from timberland

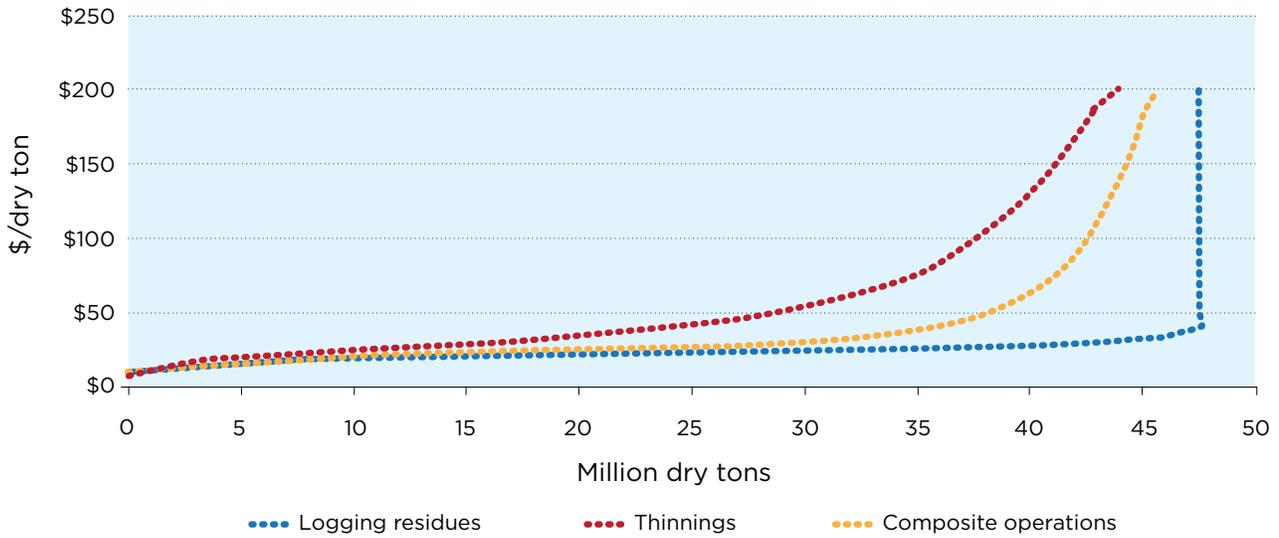


Figure 3.7 Current and year 2030 state quantities of logging residue available annually at \$80 per dry ton

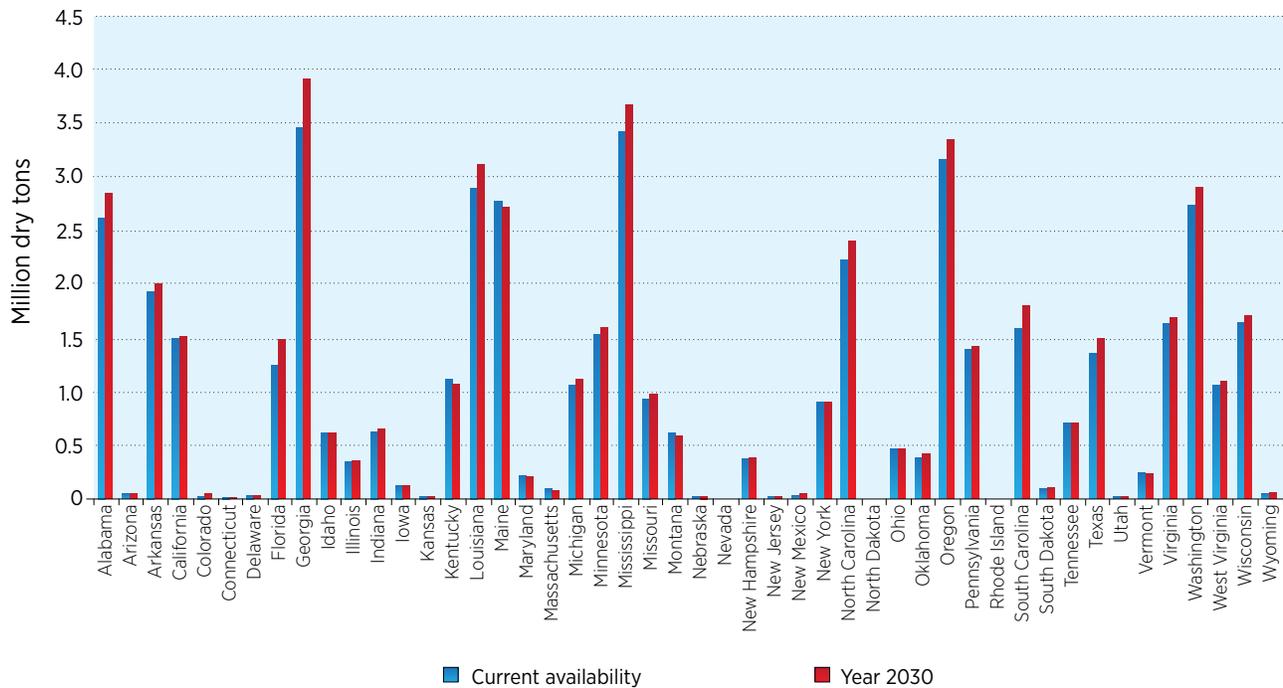
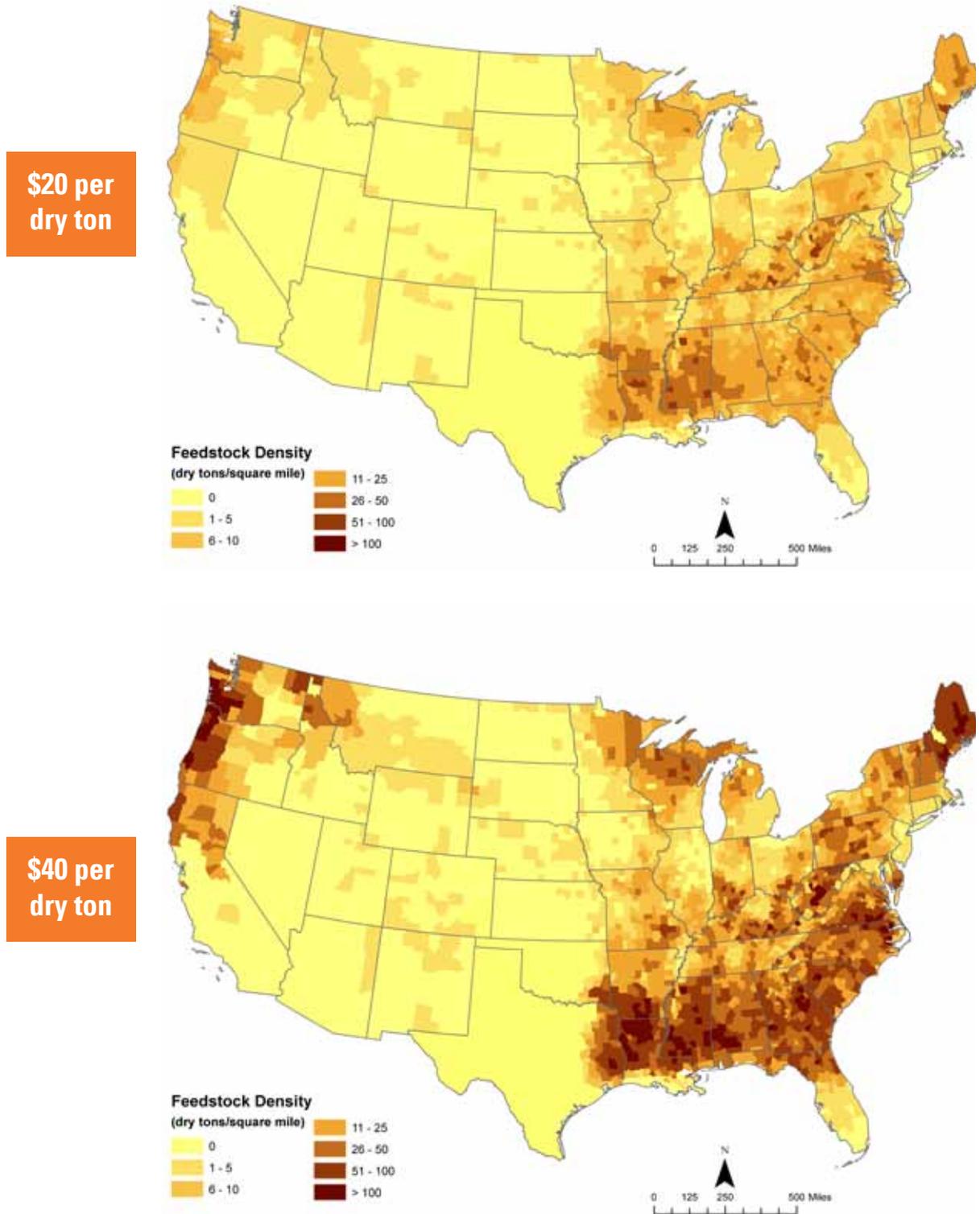


Figure 3.8 Spatial distribution of logging residues at \$20 and \$40 per dry ton (delivered to roadside)



Simulated forest thinning-based estimates. The second method used to estimate biomass supply by county is to simulate uneven age thinning operations on all non-reserved timberland in the United States using USDA Forest Service forest inventory and analysis (FIA) plots (Smith et al., 2009).²³ The data were accessed from the publicly available Forest Inventory Database on February 3, 2010 (USDA Forest Service, 2010a;b). Because the database is dynamic (i.e., is updated as states report new data during the year), accessing the database after that date gives different results. The *BTS* only estimated the biomass from fuel reduction treatments on two specific classes of most overstocked stands that needed mechanical thinning to reduce fire risk. The new method included all non-reserved forestlands, and if the stands were overstocked above certain densities, the stands were thinned regardless of the fire-risk classification (see Text Box 3.5). Decades of fire prevention and suppression efforts across the United States, especially in western areas, have led to overstocked stands and an accumulation of fuels that are increasing the risk of catastrophic fire. In the past, fire-adapted forests had relatively open canopies due to frequent low-intensity fires and harvestings intervals. Today, many stands have closed canopies and a buildup of high levels of small stems and biomass due to fire suppression and less harvesting. Highly dense forests are also stressed, which is compounded by more frequent and longer drought intervals. These conditions reduce the resistance to insects and diseases.

These forests contain significant levels of carbon sequestered in the biomass of the dense stands. Conducting fuels treatment (i.e., reducing the biomass), can release the stored carbon. If using biomass for energy, there is a displacement of fossil carbon emissions with emissions from renewable feedstocks. Furthermore, the treated stands respond to the lower density, and the trees grow quicker than when stagnated, thus sequestering carbon.

TEXT BOX 3.5 | BIOMASS EQUATIONS IN FIA

The USDA Forest Service Forest Inventory and Analysis Database (FIADB, version 4) as downloaded on February 3, 2010, is used to develop logging residues, thinnings, and conventional wood biomass estimates (USDA Forest Service, 2010a). Logging and other removal residue data is obtained from the 2007 RPA Timber Products Output (TPO) database (USDA Forest Service, 2007a). These estimates include the small tree volumes (1–7 inch diameter at breast height (dbh) in the East and 1–9 inch dbh in the West) and the non-merchantable (limbs, tops, and unmerchantable bole) volumes of the merchantable trees greater than 7 or 9 inches dbh. [Note: the updated *BTS* uses 5-inch dbh limit in the East and 7 inches in the West, which are conservative estimates.]

In August 2009, the Forest Service adopted a new method, the component ratio method (CRM), for calculating the non-merchantable volumes of the merchantable trees. In the original *Billion-Ton Study*, these volumes were calculated using diameter-based, regional prediction equations of tree volumes and biomass in components of the tree. It became apparent in the analysis that the estimated biomass component of the merchantable trees is considerably less using the new database with the CRM method compared to the old method. It is reported that the biomass estimates in tons per acre are consistently lower using the CRM compared to the regional prediction equations (Heath et al., 2009).

The change in biomass methodology to CRM produces total U.S. tree biomass inventory estimates that are 6% to 8% lower compared to estimates using the previous method. More importantly, there are significant reductions—up to 30%—for certain species, stand types, and locations. This change in method also decreased estimates of county-level biomass supply at given prices. The new methodology was used in this analysis. The reason to point out the use of the new methodology is to indicate that change lowers the estimated biomass available from thinnings and conventional harvest for those who may want to make comparisons to the original report.

²³ The FIA program has been in continuous operation since 1928. It collects, analyzes, and reports information on the status and trends of America's forests: how much forest exists, where it exists, who owns it, and how it is changing. The latest technologies are used to acquire a consistent core set of ecological data about forests through remote sensing and field measurements. The data in this report are summarized from over 100,000 permanent field plots in the United States.

Note: The most recent inventories of the 48 states state that there are 300,900 plots of which 117,875 are forested.

Hurteau and North (2009) reported that when including wildfire forecasts in a carbon emissions model, there were more potential greater emissions from untreated stands than treated stands. Their conclusion was that in wildfire-prone forests, tree-based carbon stocks were best protected by fuel treatments.

Thinning is used to reduce density, open up the stands, and improve resiliency to fire and pests. Uneven-aged thinning reduces catastrophic fire risks (Huggett et al., 2008) and provides other values as well, so it was used as a model treatment across all stands. In actual practice, the type of stand treatment is prescribed based on current conditions and desired future conditions.

Uneven-aged thinning removes trees across all age classes. This type of harvesting provides bioenergy feedstocks at the lowest cost because biomass is removed in combination with the removal of larger trees for pulpwood and sawlogs. Otherwise, harvest costs would be considerably more if fuel treatment operations were focused solely on smaller-sized trees. In addition, an uneven-aged treatment appears more likely to achieve fire-risk reductions (Skog et al., 2006). Before simulations are conducted, FIA plots located in reserved and roadless areas were excluded and assumed unavailable for treatment.

The uneven-aged thinning simulation was done on all FIA plots where the plot stand density index (SDI) was greater than 30% of a maximum SDI for that given forest type (Shepperd, 2007).²⁴ This simulates harvests to reduce fire hazard and to improve forest health on overstocked stands. Uneven-aged thinnings are simulated, and estimates are made of the amounts of biomass, pulpwood, and sawtimber that are removed.²⁵ Beginning with a 1-inch dbh trees, a treatment successively removes fewer trees from each diameter class where the removals bring the SDI down to 30% of the identified maximum SDI value for that stand

type. For the North and South, biomass removals include all wood from trees 1 to 5 inches dbh and tops and branches of trees greater than 5 inches dbh, except for wood left for retention purposes. For the West, biomass removals include all wood from harvested trees 1 to 7 inches dbh and tops and branches of trees greater than 7 inches dbh. It is assumed that all of the small-tree biomass can be extracted to roadside, but only 80% of the volume in tops and branches of larger trees will make it to roadside because of breakage. Again, a percentage of this material is retained onsite.

In estimating the cost of biomass from thinnings, it is assumed that:

- Biomass from federal lands have no stumpage costs
- Biomass from private lands range from \$4 per dry ton to 90% of regional 2007 (circa 2006–2008) pulpwood stumpage prices
- Limbs, tops, and cull components of merchantable trees have a chipping cost (harvest cost, i.e., felling and transport to roadside, are borne by the merchantable bolewood) and stumpage cost
- Small, unmerchantable trees and dead trees have harvest, chipping, and stumpage costs.

Harvest costs are estimated by the FRCS model plus costs for chipping and stumpage (Fight et al., 2006; Dykstra et al., 2009).²⁶ The 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 in the model only when the average ground slope exceeds 40%.

²⁴ SDI (Reineke, 1933) is a long established, science-based forest stocking guide for even-aged stands that can be adapted to uneven-aged stands (Long and Daniel, 1990) using data available from broad-scale inventories.

²⁵ All the biomass wood is assumed to be residues or byproducts, lacking a higher value than energy wood, except for the conventionally sourced wood. Wood that would normally be used in higher value products (e.g., pulpwood, posts, and piling,) could be used for biofuels when prices for alternate uses are lower. Also, within the lower merchantable limits, small-diameter material can easily shift between conventional, commercial uses and biofuel feedstocks, depending on prices and other factors.

²⁶ The original FRCS model was designed to simulate harvests in the Interior West. It was substantially revised for this study, including the development of new harvesting procedures designed to simulate harvests in the North and South and in the wetter areas of the West. when prices for alternate uses are lower. Also, within the lower merchantable limits, small-diameter material can easily shift between conventional, commercial uses and biofuel feedstocks, depending on prices and other factors.

To simplify the analysis, it was assumed that all the thinnings would be uneven-aged management treatments with whole-tree harvesting. This combination was determined to be the least-cost means to harvest biomass from small trees, branches, and tops. Currently, some stands are being thinned by cut-to-length systems, where the limbs and tops are processed and left in the stand. It is expected that the use of such systems will continue, if not increase, in the future, and biomass will be recovered in a second pass. This approach could be costly. The assumption of using whole-tree logging, either ground based or cable, is more indicative of how biomass will probably be recovered as part of thinning applications over the next 20 years. Because there are very few cut-to-length systems compared to whole-tree systems, the assumption in the analysis is that all thinning is done by whole-tree systems.

In the 2005 *BTS*, the fuel treatments were assumed to occur where there is road access; reduction factors were used to exclude land without current road access. In this update, the FRCS uses an FIA variable, “distance to road,” to estimate harvest cost. Although the biomass that is not near an existing road is not excluded as in the earlier assessment, the biomass is prohibitively expensive—well over \$200 per dry ton. (See Text Box 3.6 for more information on federal versus private land estimates.) These high costs occur when biomass is harvested with cable systems over 1,300 feet from an established road and ground-based systems between 0.5 and 1.0 mile from a road.

Stumpage price is developed using the following assumptions: (1) price is zero for biomass from federal land because removal is usually part of commercial sales or treatment contracts, and (2) biomass from private lands begins at a low of \$4 per dry ton and increases linearly up to a maximum that was set to be 90% of the derived pulpwood stumpage price for private land (Table 3.2).

Because the simulated thinnings also include the removal of timber for merchantable products, there is a limit as to how much can be harvested depending

TEXT BOX 3.6 | FEDERAL LAND ESTIMATES

It is important to note that the “federal land” biomass estimates are not obtained by subtracting “without federal land” from “all land.” It is only an approximation because the two values are simulated using composite plots that differ due to costs and sawtimber/pulpwood or sustainable allowable cut cap limits. Biomass estimates for each county were generated based on the lowest cost at the given supply curve costs without either exceeding the mill capacity or the net growth allowance for that county.

Cost differences were primarily dependent on distance from road and stand structure (more merchantable trees reduced costs). In many cases, the biomass from federal land was more costly because of greater distance to road and because of the high volume of small-diameter trees—this resulted in generally more wood from non-federal land. For example, 72% of the biomass less than one-half mile from the road was on private land.

Although there was no analysis completed, it is speculated that the federal lands have less cumulative biomass because of the sawtimber cap. Counties with large amounts of federal land tend to have fewer mills and conversion facilities. There may be high amounts of biomass that could not be harvested because there were no markets for the conventional products.

on mill capacities and markets for the products. This thinning removal limit is assumed to be met when the simulated removal of sawlogs plus pulpwood reaches the 2006²⁷ level of total sawlog and pulpwood harvests. This state-level restriction is to ensure that the estimated biomass supply from integrated operations can be supported by the recent (2006) level of sawlog and pulpwood harvest in each state. The impact of this assumption can be significant, reducing the amount of available biomass by up to 97%²⁸ in some states.

In preparing the overall estimate of biomass provided from integrated harvesting, it was assumed that the simulated thinnings would provide half of the harvest needed to meet sawlog and pulpwood needs. The other half of harvest would be done in a conventional way

²⁷ Harvest data is from 2006 and is taken from Table C5B (USDA Forest Service 2007a).

²⁸ The U.S. average percentage of biomass from thinnings not available because of not having roundwood markets is about 35%, calculated at \$60 per dry ton. Regional percentages are South – 5%; Pacific Coast – 18%; North – 48%; Interior West – 49%. States range from 0–97% of the biomass from thinnings not being counted in the assessment because there was not a market in the state for the associated roundwood.

and generate logging residue, a portion of which can be removed for bioenergy. There is also the potential that the markets for sawlogs and pulpwood will expand as the current 2005 RPA Timber Assessment reflects (Haynes et al., 2007). The amount of estimated biomass supply from integrated harvesting (half from conventional harvesting, half from thinning simulations) is increased over time by the rate of increase in projected sawlog plus pulpwood harvest from the 2005 RPA Timber Assessment. A note about special situations of available biomass is provided in Text Box 3.7.

The Biomass Treatment Evaluator was used to estimate county-level supply curves for biomass and industrial roundwood removals on FIA plots by assigning stumpage prices and harvest and chipping costs using the FRCS model.²⁹ Finally, simulated amounts of biomass supply are assumed to be harvested over a 30-year period. This is the same period assumed for thinnings estimates provided in the 2005 *BTS* report.

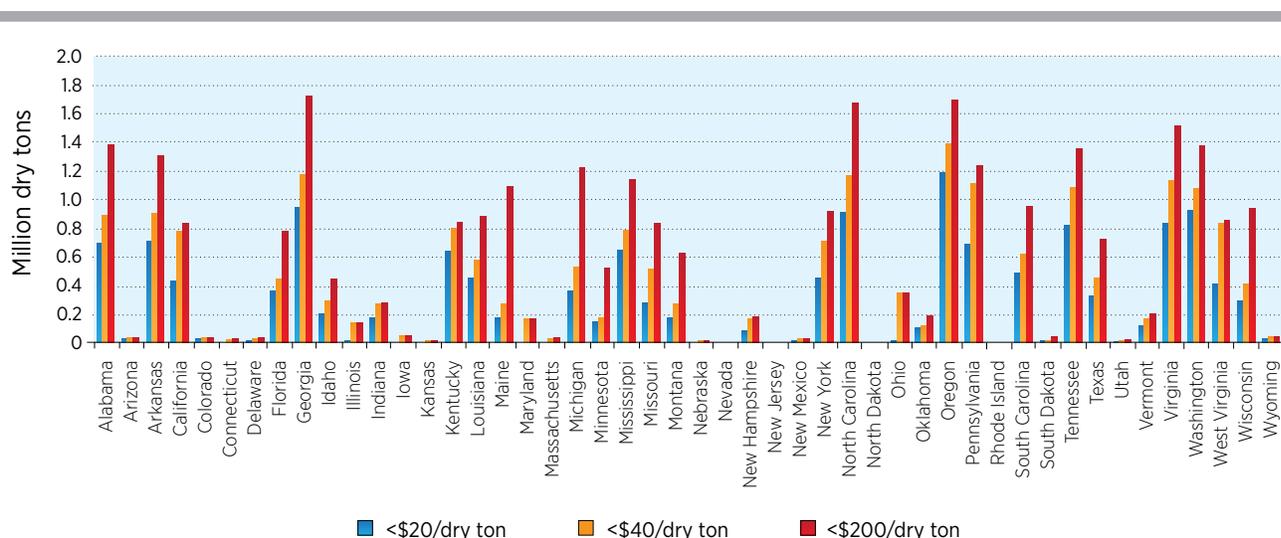
The national supply curve for simulated forest residue thinnings on timberland is shown in Figure 3.6. The total simulated quantity is about 37 million dry tons per year at a roadside price of \$100 per dry ton or less (Table 3.3). About 24 million dry tons annually are available at a roadside price of \$40 per dry ton or less; at \$60 per dry ton, about 32 million dry tons are

available. Table 3.4 shows that there are no differences over the next 20 years in biomass availability because the thinnings are averaged over 30 years. State quantities are shown in Figure 3.9 at three different roadside costs, with more spatial detail provided in Figure 3.10.

In the 2005 *BTS*, the fuel treatments were assumed to occur where there is road access; reduction factors were used to remove land without current road access. In this update, the FRCS uses an FIA variable, “distance to road,” to estimate harvest cost. Although the biomass that is not near an existing road is not excluded as in the earlier assessment, the biomass is prohibitively expensive—well over \$200 per dry ton. These high costs occur when biomass is harvested with cable systems over 1,300 feet from an established road and ground-based systems between 0.5 and 1.0 mile from a road.

Stumpage price is developed using the following assumptions: (1) price is zero for biomass from federal land since part of commercial sales or treatment contracts, and (2) biomass from private lands begins at a low of \$4 per dry ton and increases linearly up to a maximum which was set to be 90% of the derived pulpwood stumpage price for private land (Table 3.2).

Figure 3.9 State quantities per year of simulated forest thinnings at \$20, \$40, and \$100 per dry ton (roadside)



²⁹ The Biomass Treatment Evaluator—an SAS® (Statistical Analysis Software) program prepared by Patricia Lebow, USDA Forest Service Forest Products Laboratory—was used to prepare county-level supply curves.

TEXT BOX 3.7 | DEAD AND DYING TREES

A potential feedstock for energy is the dead and dying trees associated with mortality from insects, disease, fire, wind, and other disturbances. In any particular year or period of years, there could be considerable volumes “available” as biomass for energy. A significant issue associated with this feedstock is the inconsistency of the annualized volumes within a designated landscape over a long term and high costs associated with the recovery and utilization of such biomass. There is considerable variation in acres affected annually, especially from pests (Figure 1), and the severity of the damage. In 2008, nearly 9.0 million acres of mortality was caused by insects and disease nationally, a 2.2-million-acre increase from 2007, when 6.8 million acres of mortality were reported (USDA Forest Service, 2009).

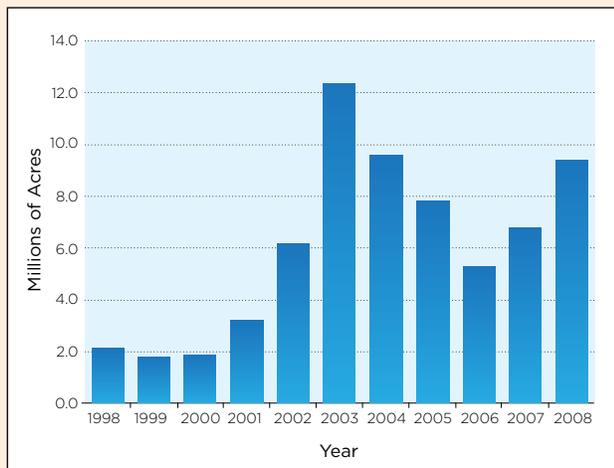


Figure 1

Survey of insect and disease mortality (*Courtesy of USDA Forest Service*).



Figure 2

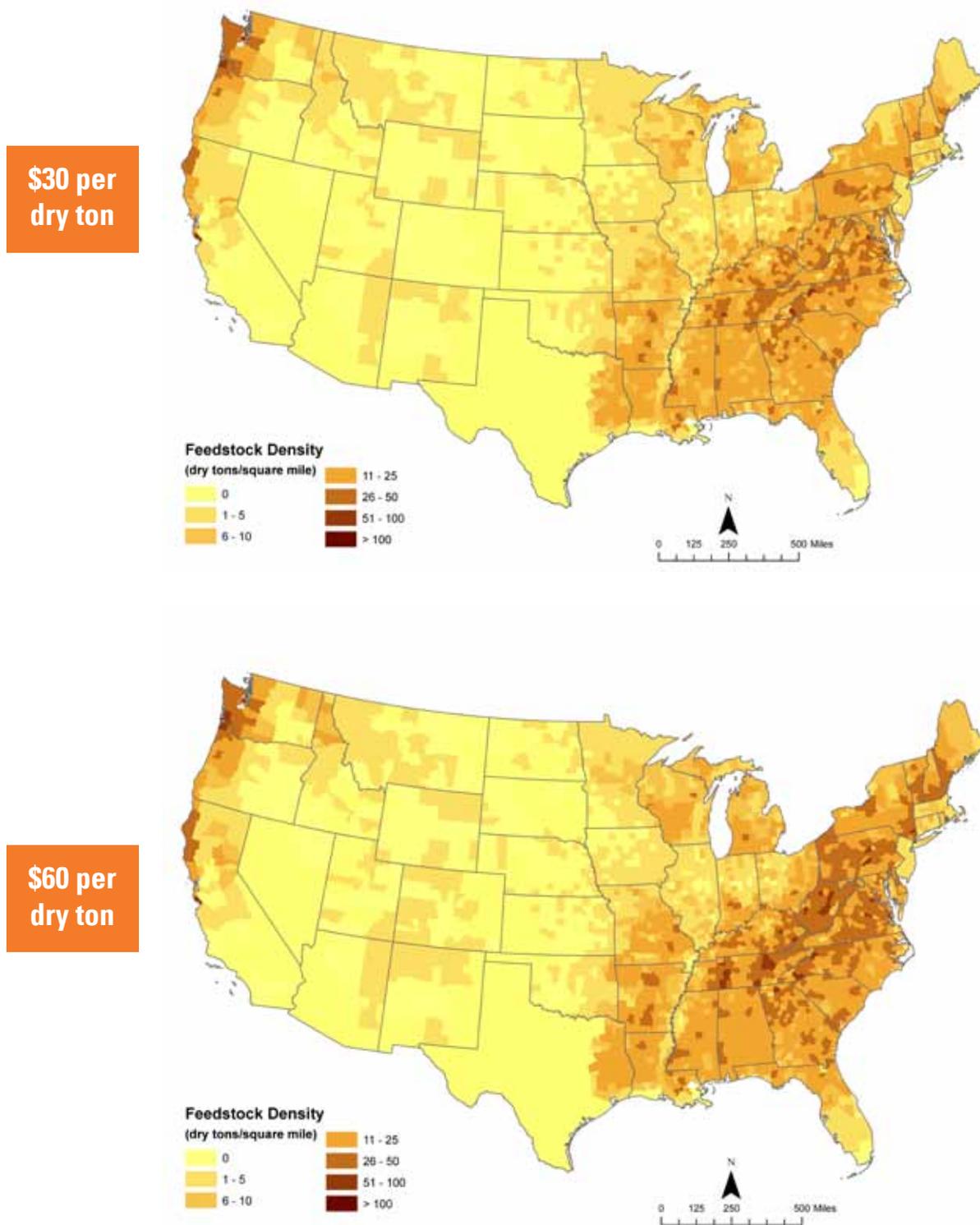
Pine beetle infestation in Colorado, 2007 (*Courtesy of USDA Forest Service*).

However, there is growing concern about the increasing insect epidemics in the western United States and their transition to other areas of the country. For example, in the reported 2008 insect and disease mortality, nearly 69% of the mortality was caused by just the mountain pine beetle. The mountain pine beetle, *Dendroctonus ponderosae*, is a native species currently experiencing large-scale outbreaks in western North American pine forests—from Baja California in Mexico to central British Columbia in Canada. It affects primarily lodgepole pine, but also ponderosa and other pines (Figure 2). The beetles have killed more than 2 million acres of lodgepole pines across Colorado and southern Wyoming alone. Cold winters, which Colorado has not seen for years, are needed to kill the larvae and wetter summers are needed to help the trees resist the pests.

Over the past several years, widespread outbreaks of native bark beetles have occurred across the western United States, from pinyon woodlands to spruce-fir forests. The severity and distribution of the recent outbreaks is more than what can be inferred from historical records. The changing climate has given pests the opportunity to invade what has been inaccessible forest habitat (Logan, 2007).

With the known increase in widespread tree deaths from insect epidemics, the issue is whether there should be an additional analysis of the potential wood supply from these epidemics. It was decided that the use of the FIA database and the methodology to address thinnings and logging residues sufficiently included the dead and dying trees. The FIA delineates recently dead and long-standing dead trees on all plots. The current western data averages the number of mortality trees over a 5-year period (Thompson, 2009). A real annual number will not be available until all inventory panels (percentage of all state plots) are completed over 10 years for each state. The “annualized” mortality in the FIA database was thought to be a better estimate of the mortality than an additional analysis, which would be subject to assumptions in both severity and distribution and would have high variability. Because mortality is already incorporated into the assessments using the FIA database, no additional analysis was needed.

Figure 3.10 : Spatial distribution of simulated forest residue thinnings at \$30 and \$60 per dry ton (roadside)



(Courtesy of ORNL)

Composite integrated operations supply estimates.

As explained in an earlier section, the logging residue estimates are based on the continuation of current conventional harvesting practices (i.e., merchantable stand and tree components are removed and the residues are left onsite). When estimating both logging residues and simulating integrated thinnings, there will be “double counting of biomass” because the TPO projections used to estimate logging residues do not take into account any reductions in logging residues over time, as more stands are harvested using integrated systems. The conceptual transition from leaving the biomass as logging slash to removing it when the merchantable timber is harvested is likely to occur in response to the development of biomass markets. As it is difficult to model the transition, an assumption had to be made to avoid counting the biomass as both logging residues and integrated thinning biomass. A

conservative estimate is 50% of the logging residue supply estimates and 50% of the thinning supply estimates, which means that over the time of the projection, about half will come from the recovery of logging residues and half from thinnings. The composite operations supply curve is shown in Figure 3.6 and Figure 3.11. The curve is generally similar to the logging residue supply, owing to the assumed 50:50 ratio of logging residue to simulated forest residue thinnings. Almost 36 million dry tons per year are available at a roadside price of \$40 per dry ton or less (Table 3.3); at \$60 per dry ton, the annual potential volume is about 40 million dry tons. When federal land is removed, the amount is reduced by about 5 million dry tons per year. About 41 million dry tons are available in 2030 at \$60 per dry ton from all lands. The residues from integrated operations by state are shown in Figure 3.12 at an example price of \$80 per dry ton.

Figure 3.11 : National supply curves for integrated harvesting operations

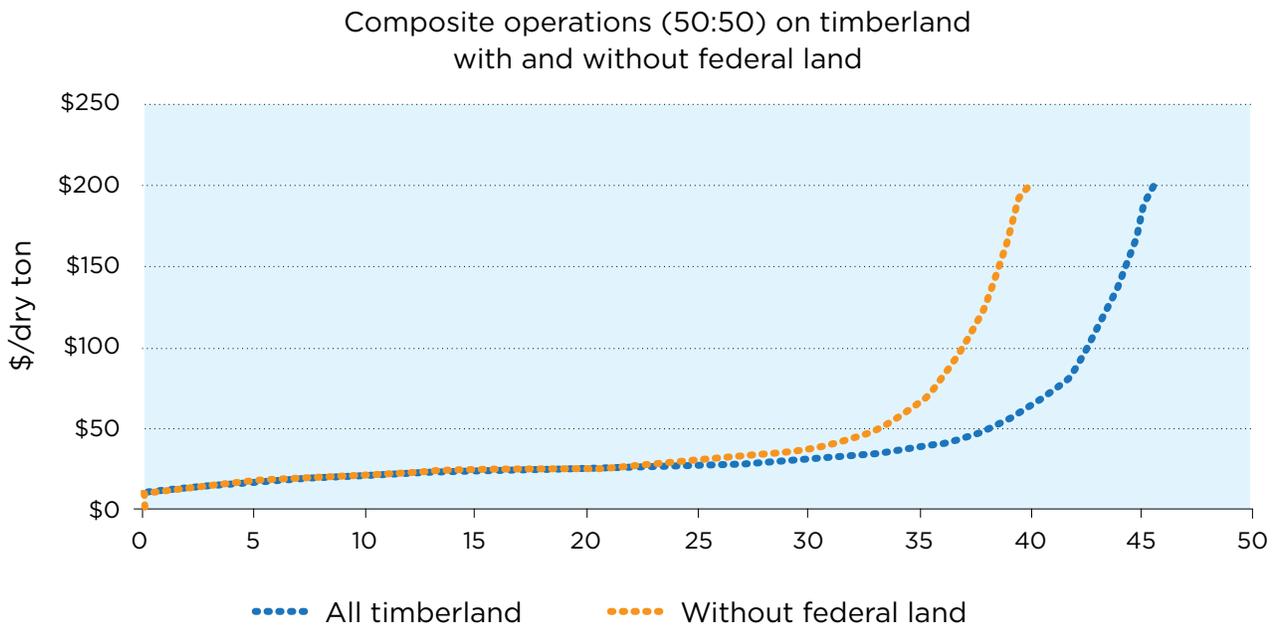
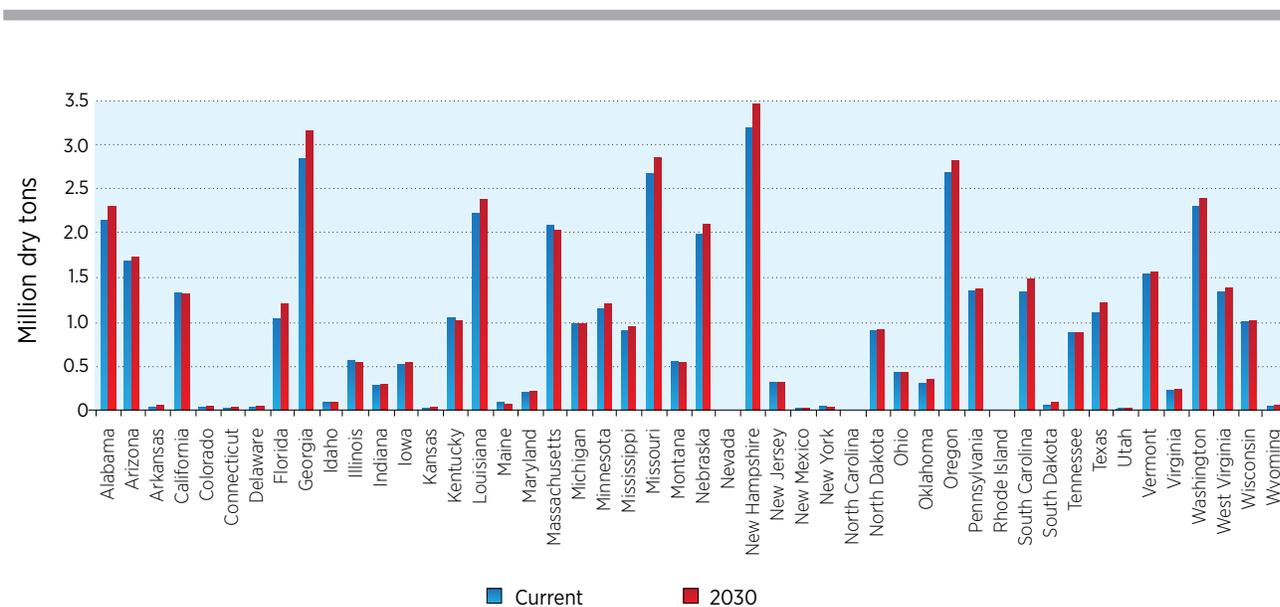


Figure 3.12 : Current and year 2030 state integrated operations quantities per year at \$80 per dry ton or less at roadside



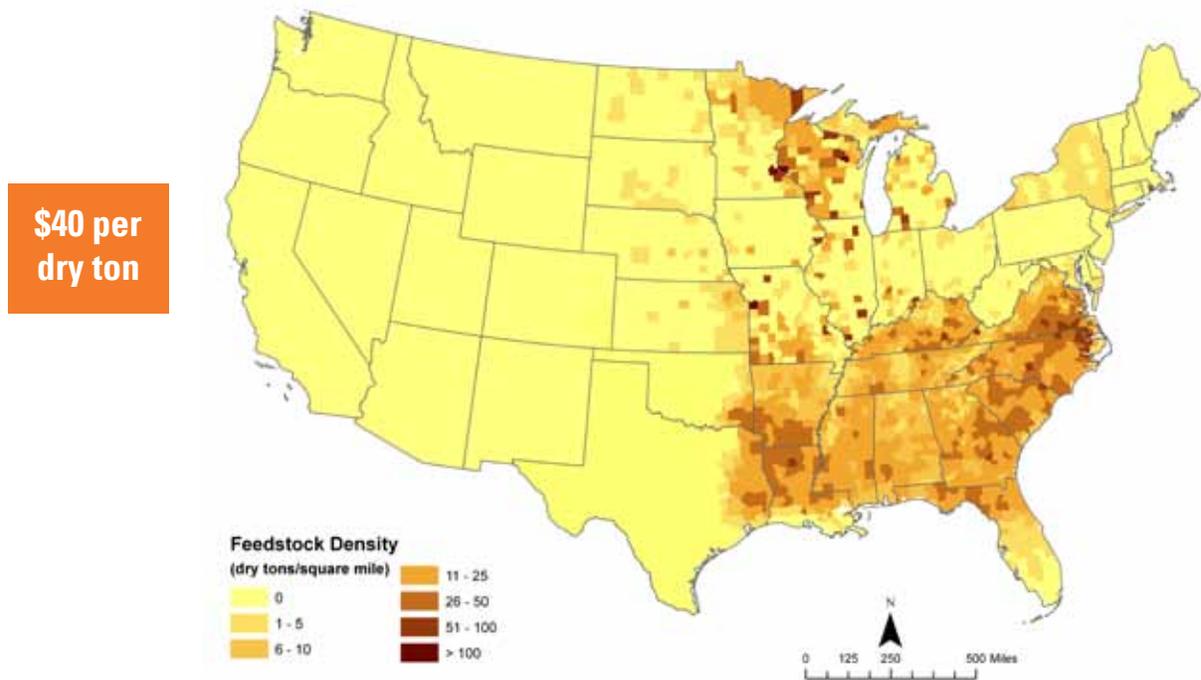
3.2 Other Removal Residues

The conversion of timberland to non-forest land uses (cropland, pasture, roads, urban settlements, etc.) and precommercial thinning operations generates a relatively significant amount of forest residue biomass. These “other removals,” especially from land-clearing operations, usually produce different forms of residues and are not generally as feasible or as economical to recover. It is expected that only half of the residues from other removals can be recovered.

Amounts of other forest removals, by county, are obtained from the TPO database for 2007 (USDA Forest Service, 2007a). The 2005 *BTS* report assumed that 50% of the TPO residue estimate is recoverable and available. The original estimate was based on discussion with experts concerning the level of difficulty of recovering this feedstock. Specific characteristics of this feedstock, small land areas, and trees pushed up and piled, trees cut into small pieces, etc., make it difficult to recover them fully. The

50% recoverable assumption is used in this update as well. There is little price data available for these types of feedstocks. Assumptions are made based on the expertise of the contributing authors concerning recovery and transport costs and market prices to derive the stumpage values. Specifically, one-third is assumed to be available at \$20 per dry ton (roadside) and the remainder at \$30 per dry ton at roadside. So at \$60 per dry ton or less, about 12.4 million dry tons are available (see Table 3.3). Future estimates of other removal residue are based on RPA projections of timberland area. Through 2030, total timberland area is projected to decline by about 6 million acres, which could mean that there could be more “other removals.” Table 3.4 does not show an increase in recovery of this biomass and keeps potential tons available at 12.6 million per year. Figure 3.13 shows the availability across the United States for residues from other removals.

Figure 3.13 : Spatial availability of other removal residues at \$40 per dry ton (delivered to roadside)



(Courtesy of ORNL)

3.3 Forest Residue Thinnings on Other Forestlands

Other forestlands are defined as incapable of producing at least 20 cubic feet per acre per year of industrial wood under natural conditions because of a variety of adverse site conditions, ranging from poor soils, lack of rainfall, and high elevation. Many of these woodlands (low-stature or sparse forests) are in the western states and are overstocked, especially with stands of pinyon pine and juniper. As with the fuel reduction thinnings on timberland, removal of the excess biomass could greatly reduce catastrophic fire hazards. FIA data (USDA Forest Service, 2010b: accessed on February 3, 2010) was used to identify overstocked western woodlands. Similar assumptions the 2005 *BTS* report were used for the update. In Table 3.3, the total residue biomass from thinning other forestlands was estimated at 3.2 million dry tons at a price of \$60 per dry ton

(none are expected to be available below this price because of the high cost of thinning other forestlands). Above \$80 per dry ton, 6.4 million dry tons annually becomes available for all lands. When federal forestlands are removed, only 3.6 million dry tons are available, which is a 50% reduction. By definition, these lands do not produce commercial-sized pulpwood or sawlogs, so the cost of removing the thinnings is borne fully by the biomass harvesting operation. An assumption used in the analysis was that about 50% of the biomass could be removed at a price of \$60 per dry ton and the remainder at a price of \$70 per dry ton. Again, these assumptions are the best estimates by the contributing authors with knowledge in these types of systems. The estimates are considered conservative as they represent the high end of thinning costs because no higher-valued wood is removed with the biomass.

3.4 Fuelwood, Mill Residues, and Pulping Liquors

3.4.1 Fuelwood

All currently used fuelwood is shown in Table 2.1 and is estimated to be 38 million dry tons per year. The quantity of fuelwood used for residential and

commercial space heating applications, as well as feedstock for dedicated wood-fired facilities and co-firing applications, is projected to increase to 106 million dry tons per year by 2030.

3.4.2 Primary and Secondary Mill Residues

Amounts of wood and bark residue from milling operations (by county) are obtained from the TPO database for 2007 (USDA Forest Service, 2007a). For the baseline case, it is assumed that only unused mill residues are available (see the discussion in Chapter 2 concerning “used” primary mill residue). Neither the Forest Service nor any other federal agency systematically collects data on secondary mill residue. One of the few estimates of the amount of secondary mill residue available is provided by Rooney (1998) and subsequently revised by Fehrs (1999). Fehrs estimates that about 15.6 million dry tons is generated annually, with about 40% of this potentially available and recoverable. The remaining fraction is used to make higher-valued products, is used onsite to meet some energy needs (such as heat for drying operations), or is not available for other reasons. Table 2.1 provides projected consumption of currently used primary and secondary mill residue. Currently, there are about 32 million dry tons being used, mostly for energy. It is estimated that by 2030, 42 million dry tons will be consumed.

For the unused remaining mill residue, it is assumed that these residues can be purchased at the mill for \$20 per dry ton or less, which is comparable to the disposal

cost if there are no markets available. Delivered prices could be much higher, especially for secondary mill residue where facilities are small, dispersed, and operate seasonally (Figure 3.14). Table 3.3 shows that there are 1.3 million dry tons of primary mill residues and 6.1 million dry tons of secondary mill residues annually at this mill price. It is assumed that any residue associated with increased future demand for primary and secondary wood products is offset by greater mill efficiencies and a continued increase in the use of this material for byproducts. At a price above \$60 per dry ton, the total available used and unused mill residue is about 40 million dry tons. There are no scenarios beyond the baseline.

Figure 3.14 : Conversion facility



(Courtesy of ORNL)

3.4.3 Pulping Liquors

As explained in Chapter 2, the combustible chemical byproducts, such as black liquor from pulping facilities, are currently used for energy production and

are not counted as an additional feedstock resource. The available amount is 45 million dry tons, with projections to 58 million dry tons in 2030.

3.5 Urban Wood Wastes

The two major sources of urban wood residues are the woody components of MSW and C&D waste wood. MSW source consists of a variety of items, ranging from organic food scraps to discarded furniture, packaging materials, textiles, batteries, appliances, and other materials. In 2007, 254 million tons of MSW were generated (EPA, 2008). About 54% of the total quantity generated was discarded in municipal landfills. The remainder was either recycled, made into compost, or combusted for energy recovery. Containers and packaging are the single largest component of MSW, totaling some 78 million tons, or 31%, of the total. Durable goods are the second largest portion, accounting for 25% of total MSW generated. Yard trimmings are the third largest portion and account for about 33 million tons, or 13%, of the total.

The wood component of containers and packaging and durable goods (e.g., lumber scraps and discarded furniture) is slightly more than 14 million tons (EPA, 2008). According to Falk and McKeever (2004), about 10% of this material is recycled and 22% is combusted for energy recovery. The remaining material is discarded and land filled. About one-third of this discarded material is unacceptable for recovery because of contamination, commingling with other wastes, or other reasons, such as size and distribution of the material (McKeever, 2004). The remainder that is potentially available for bioenergy totals about 5.7 million dry tons annually.

Yard and tree trimmings are the other woody component of MSW. Currently, about 32 million tons are generated annually, with nearly 21 million tons of this amount recovered (EPA, 2008). In this update, an additional 4.3 million dry tons of wood is assumed recoverable and available for bioenergy applications after accounting for quantities that are likely to be composted, combusted, recycled, or contaminated and unavailable. The fractions composted, combusted, and contaminated are based on technical coefficients developed by McKeever (2004).

The other principal source of urban wood residue is

C&D debris. C&D wood waste is generated during the construction of new buildings and structures, the repair and remodeling of existing buildings and structures, and the demolition of existing buildings and structures (McKeever, 2004). These materials are considered separately from MSW because they come from many different sources. These debris materials are correlated with economic activity (e.g., housing starts), population, demolition activity, and the extent of recycling and reuse programs. The updated estimates of C&D debris wastes total about 21.7 million dry tons. About 9.4 million dry tons are construction debris, and 12.2 million dry tons are demolition debris. These estimates are based on technical coefficients developed by McKeever (2004). They are slightly higher than the 2005 *BTS* estimates because of changes in population and economic activity.

MSW wood waste along with C&D debris together sum to nearly 32 million dry tons per year as potential energy feedstocks. As noted by McKeever (1998), many factors affect the availability of urban wood residues, such as size and condition of the material, extent of commingling with other materials; contamination; location and concentration; and costs associated with acquisition, transport, and processing. A map of urban wood wastes availability is shown in Figure 3.15.

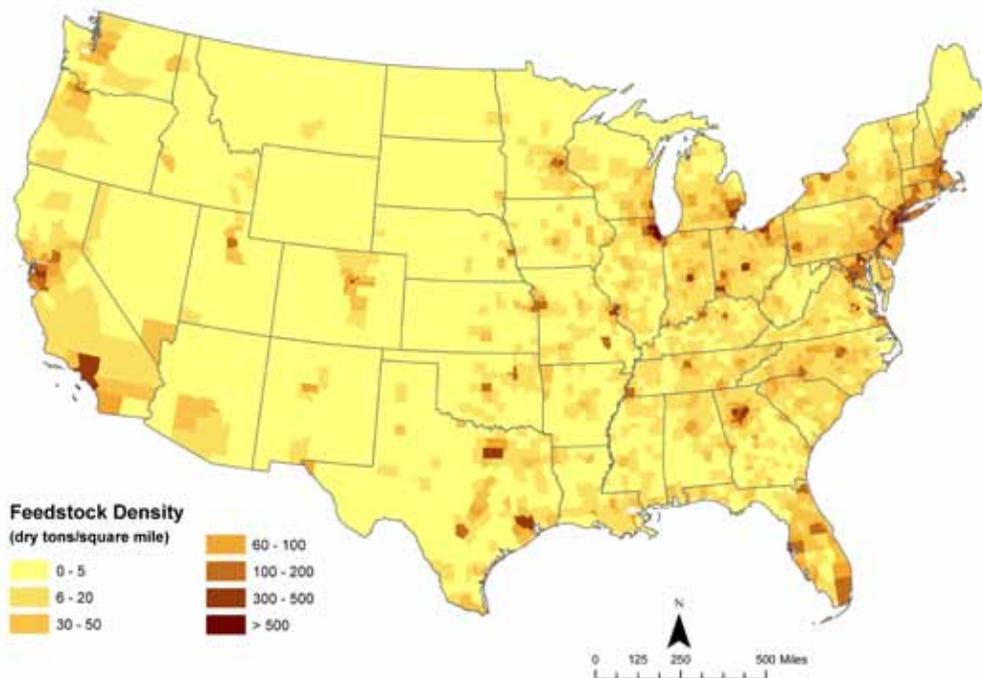
In the previous chapter (Table 2.1), the currently used MSW wood was estimated at 14 million dry tons annually and projected to increase to 20 million dry tons per year by 2030. In this chapter, the unused MSW wood and yard trimming wastes total 10 million dry tons; and, the unused C&D debris wood could provide an additional 21.7 million dry tons. Future quantities of unused urban wood wastes (MSW and C&D sources) will no doubt rise as population increases; however, the increase will likely be less owing to ongoing waste recovery efforts and higher landfill disposal costs. For construction waste, it is likely that higher fractions will be recycled and reused, and there will be greater use of engineered lumber, which will reduce dimensional lumber use and also make less waste available. For demolition wastes, improved recycling and reuse efforts should lead to increases

in the number of buildings deconstructed as opposed to demolished, which will tend to lower quantities of waste wood available for bioenergy. For these reasons, future quantities of urban wood wastes are assumed to increase at one-half of the rate of population growth.

Table 3.3 shows the supply schedule for urban wood wastes by MSW and C&D categories. As noted, the total potential resource is estimated at 10 and 21.7 million dry tons for MSW wood wastes and C&D wood waste at prices greater than \$60 per dry ton, respectively. As explained by Walsh (2006), the quantity of urban wood wastes available at given prices depends on many factors. Chief factors include whether the materials are collected as mixed wastes or are source separated and the prevailing landfill tipping fees (i.e., the levelized costs of operating a landfill). Prices to acquire these materials could be very low if collected as mixed wastes and where landfill tipping fees (avoided costs) are high. In this update, the prices

to acquire urban wood wastes are based on the results of Walsh (2006). The report assumes that about 75% of the MSW wood waste can be acquired for \$20 per dry ton or less, 85% at \$30 per dry ton or less, and 90% at \$40 per dry ton or less. All of the identified MSW wood is assumed to be available at \$60 per dry ton or less. For C&D wood wastes, it is assumed that 20%, 50%, 65%, and 100% are available at \$20, \$30, \$40, and \$60 per dry ton, respectively. In total, MSW wood is about 24 million dry tons at \$60 per dry ton or less. This quantity includes the 14 million dry tons currently used (Chapter 2) and 10 million dry tons of unused MSW wood wastes. In addition, there are 21.7 million dry tons of C&D wood wastes for a total of 45 million dry tons. Table 3.3 shows the urban wood waste supplies and Table 3.4 shows current and future supplies at selected prices and future years.

Figure 3.15 Spatial availability of urban wood waste (municipal solid waste and construction and demolition wood residues)



(Courtesy of ORNL)

3.6 Conventionally Sourced Wood – Pulpwood-Sized Roundwood

The 2005 *BTS*, as well as most of this update, only considers non-merchantable and waste woody resources. A final resource added to the update is conventionally sourced wood, which is wood that has a commercial value for other uses but is used as an energy feedstock instead because of competitive market conditions. In reality, only the pulpwood-sized roundwood would be used for biomass and probably just the smaller diameter pulpwood-sized trees.

If pulpwood-sized material is used as biomass for bioenergy, it will most likely be obtained through two approaches: (1) from “additional harvests” of pulpwood-sized trees and biomass together in thinning operations that are in addition to the previously discussed thinnings and (2) from a shift of wood

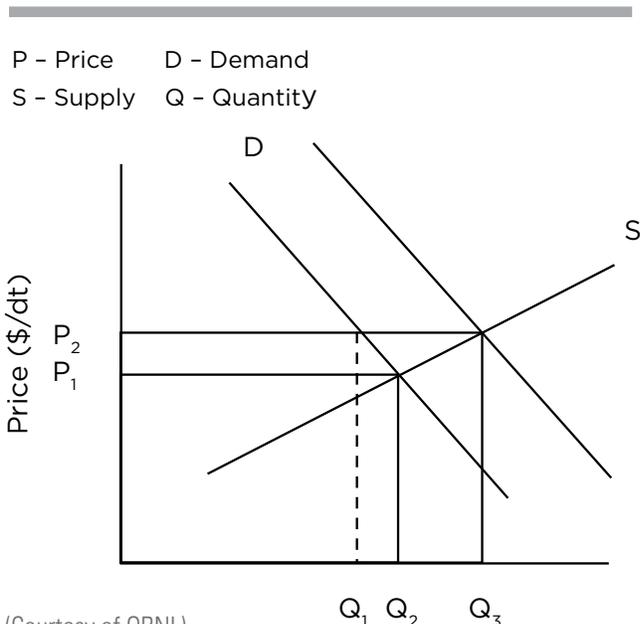
being cut for pulpwood from current uses into uses for bioenergy (i.e., “pulpwood supply”). Both are referred to as conventionally sourced wood because the pulpwood-sized trees are usually harvested for conventional products, such as paper and panels. To ensure sustainability in the additional harvests, pulpwood harvests were restricted to only removing the annual growth, which means, not reducing inventory (using the 2006 harvest levels from Smith et al. (2009)). When using pulpwood to supply bioenergy, the shift from pulpwood to bioenergy was restricted to 20% of the 2006 pulpwood harvest because of the underlying assumptions in the analyses. The assumptions are explained in the following sections.

3.6.1 Use of Pulpwood Stumpage Supply and Stumpage Demand Curves

To estimate supply from additional harvests, it is assumed that there will be additional thinning operations that are separate from integrated harvesting operations that take pulpwood-sized trees and associated biomass (tops and branches) in a given region. These additional thinning operations, in response to increasing demand for wood for bioenergy, move up the existing pulpwood stumpage supply curve (see Figure 3.16) for each state and increase the marginal stumpage price (Q2 to Q3 and P1 to P2). As the stumpage price increases, an amount of pulpwood previously demanded and used is diverted from integrated harvesting operations to bioenergy use. This corresponds to an amount obtained by shifting stumpage price upward on the pulpwood demand curve (P1 to P2 and Q2 to Q1). The simplifying assumption for the time period covered by the supply estimate is that there is little shift in the pulpwood supply curve or in the pulpwood demand curve for pulp or panel production (see Text Box 3.8). In reality, supply curves will shift with changes in the amount and age composition of timber inventory and technology. Also

the demand curve will shift with a number of drivers, including the level of Gross Domestic Product and strength of the dollar relative to other currencies, which will influence demand for pulp, paper, and composite panel exports.

Figure 3.16 Theoretical pulpwood supply model for biomass



(Courtesy of ORNL)

TEXT BOX 3.8 | ESTIMATING FUTURE SUPPLIES OF PULPWOOD FOR BIOENERGY

The conventionally sourced supply curve was developed holding the supply function constant over time, which means that supply does not change in response to changing inventory, changes in pulpwood demand for pulp and panels, or change in product imports. This approach was done for simplicity and convenience, recognizing the lack of a sufficient model to project future supply changes. Future supply of pulpwood for bioenergy will be influenced by the outward shift of pulpwood supply curves (more wood becomes available at a given cost) in each region and by shifts in demand curves (outward shift would mean an increase in demand amount for a given price).

The outward shift in pulpwood supply curves in each region will be influenced in part by increases in available inventory of pulpwood-sized trees. The 2005 RPA Timber Assessment projects increases in some regions and decreases in other regions for pole timber-sapling acres and young sawtimber acres on timberlands privately owned (Haynes et al., 2007, Table 39).

The most notable increase between 2006 and 2020 is for softwood poletimber in the North (13%) and young softwood sawtimber in the West (20%). The U.S. average change in private pole timber acres between 2006 and 2020 is minus 5% and for young sawtimber acres, plus 1%. The changes in acres through 2030 are minus 18% for pole timber and minus 2% for young sawtimber. Volume of timber could be increasing more than the change in acres coming into the timber size class because of a higher density of timber. The total inventory of sawtimber and non-sawtimber for the North, South, and West is projected to increase from 2006 to 2020 by 10%–12% and 15%–19% by 2030. These shifts in acres and inventory of standing timber would tend to shift pulpwood supply curves outward by 2030 in major regions by amounts on the order of 20%. Shifts could be larger in subregions.

The pulpwood demand curves, demand for pulp and panels, in each region will be shifted outward with increases in economic activity that demands paper (e.g., office use, shipping) and composite panel products (e.g., buildings). These outward shifts, shifts that increase demand for traditional products at a given price, will decrease biomass supply available for bioenergy and tend to offset supply increases due to outward shifts in the pulpwood supply curves. Alternately, if pulpwood demand decreases, or more pulpwood, pulp, paper, or composite panels are imported, then more of the pulpwood supply at a given price will be available for bioenergy.

Projections from the 2005 RPA Timber Assessment (Haynes et al., 2007, Table 11) indicate that hardwood pulpwood supply curves for the South would be shifting outward more rapidly than outward shifts in demand curves as evidenced by decreasing pulpwood prices through 2020, but by 2030, the outward supply shift would slow relative to outward shifting demand, and price would increase to the 2006 level. This suggests economic availability of hardwood pulpwood in the South by 2030 could be similar to 2006 if these projections are approximately correct. Projections suggest softwood pulpwood supply curves' outward shift would lag outward shifts in demand through 2020 as evidenced by the increasing pulpwood price by 2020; then, supply shifts would exceed demand shifts as indicated by the decreasing price through 2030 when price may be lower than the 2006 level.

With the current economic downturn of pulpwood demand levels, there may be less demand than projected in the 2005 RPA Assessment through 2020 or 2030. In this case, pulpwood-sized material needed for pulp, paper and panels would be less than projected. Then, more wood would be available for bioenergy, which would result in more conventionally sourced wood going to bioenergy that could match or exceed a 20% increase (for a given price) in response to a 20% increase in timber inventory.

It should be pointed out that the 2005 RPA Timber Assessment was developed without expectations of an economic downturn and notably expanding bioenergy markets. A better analysis of these dynamics will be forthcoming in the 2011 RPA Forest Resources Assessment. The updated *BTS* analysis likely indicates a conservative estimate of pulpwood supply compared to supply in the future.

Estimating pulpwood supply from additional harvest. The initial step (see Figure 3.16) to estimating county-level pulpwood supply curves from additional thinning operations is to specify a new higher regional-level stumpage price; for example, 10% higher than the base price (P1 to P2) and note the quantity obtained will move up the supply curve (Q2 to Q3). Next, the regional-level quantity of pulpwood and biomass is allocated to counties based on lowest harvest and transport costs to roadside. Each county quantity is assigned a roadside price equal to harvest cost plus the state-level stumpage price. The process is repeated for successive increases in the regional-level stumpage price to form county-level supply curves.

The pulpwood harvest prices are estimated by first simulating thinnings on higher-density (higher SDI) FIA plots using diameter-limit aged silvicultural prescriptions that gradually remove diameter classes until the SDI target is met. The thinnings only remove pulpwood-sized and smaller trees, where pulpwood-sized trees are defined as trees 5–7 inches dbh in the North and South, and 5–9 inches dbh in the West. The FRCS model is used to estimate harvest costs to remove pulpwood-sized trees plus biomass. When allocating regional pulpwood supply amount (at a given regional stumpage price) to the county level, the amount is allocated to counties using quantities and harvest costs where harvest costs are the lowest. As more pulpwood is supplied at higher regional stumpage prices, it is allocated to counties where harvest costs are higher.

A cornerstone of this method is a set of estimates for elasticity of pulpwood supply quantity and demand quantity with respect to changes in pulpwood stumpage price (obtained from a review of literature). The elasticity estimates from the literature are made using time series data where quantity and price vary over a certain range and use econometric equation forms, which limit their use and application. Typically, the price and quantity data are annual, and the percentage change in prices over the entire time series is less than 50%. Most of the econometric equation forms do not distinguish between elasticity with respect to price in the short term (roughly a year or less) versus quantity response in the long term (more than one year) where capital investments may occur that will influence

supply or demand response to pulpwood price change. Given that short-term elasticities are generally not estimated; the elasticities found in the literature reflect responses to prices that will occur over several years.

Estimated historical average pulpwood supply elasticity with respect to stumpage price for the U.S. South is suggested to be about 0.34, as indicated by results of six studies (Newman, 1987; Carter, 1992; Newman and Wear, 1993; Prestemon and Wear, 2000; Polyakov et al., 2005; Lao and Zhang, 2008). Elasticity estimates from studies that covered the entire South range from 0.23 to 0.49. These are averages for both hardwoods and softwoods for all land where most supply was from private land. While pulpwood supply elasticity estimates are not available explicitly for the North and West, an estimate within this range is consistent with estimates of supply elasticity with respect to stumpage price for all timber from two national studies (Adams and Haynes, 1980; 1996). These two studies estimate that the private timberland area-weighted national average supply elasticity for all timber in the North and West is 0.42 to 0.47. In addition, studies for the South suggest supply elasticity for sawtimber alone to be 0.42 to 0.55 (Lao and Zhang, 2008; Newman, 1987). If elasticity for sawtimber in the North and West is about 0.45, then pulpwood supply elasticity in the North and the West is about 0.3. If the sawtimber supply elasticity in the North and West is 10% higher or lower, the North and West pulpwood supply elasticity could range from 0.16 to 0.44. Given the wide range associated with these estimates, a pulpwood supply elasticity of 0.35 is used for all states.

Given that these estimates are based on large areas and that pulpwood prices are inherently locally driven, it is clear that the estimates of quantity supplied for any given price at the county level could vary notably from actual supply quantities for the given price. The estimates are only intended as an indicator of approximate supply, which may aid in determining when more local estimates are warranted. Given the uncertainty in the supply elasticity estimates and concern about sustainability of increased harvest levels, the possible annual pulpwood supply at the regional level is limited so as not to exceed the level of annual timber (growing stock) growth in each state elasticity

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Pulpwood supply estimates diverted to bioenergy use. Estimates of average pulpwood and panel wood demand elasticity with respect to stumpage price are found in two studies—for the South as a whole (-0.43) and for Texas (-0.41), respectively (Newman, 1987; Carter, 1992). An elasticity of -0.42 is used for each state. Estimates of potential pulpwood supply are made by using backward shifts along the demand curve for successive increments in pulpwood stumpage price (e.g., 10%). At each price point, the biomass amount is allocated to counties according to lowest harvest costs. Resulting county-level supply curves indicate the quantity supplied at particular total roadside prices.

The methods used to estimate pulpwood supply, although simplified, parallel the methods used to estimate amounts of biomass from integrated harvesting operations. The estimates are based on detailed analyses of harvest quantities and costs from treatments on FIA plots across the United States. The stumpage price to obtain supply amount or a currently demanded amount is estimated using basic information about the elasticities of supply or demand quantity with respect to price. These estimates should be considered

only as approximate potential supply in localized areas. The analysis is overly simplified in that it does not take into account potential inventory changes over the longer term because of investments in afforestation or significant disturbances. A model with both spatial detail and time dynamics is not available for this analysis. The estimates are only intended to be both short term and without significant inventory changes.

Given the uncertainty in the demand elasticity estimate for the nation as a whole and a higher uncertainty for a region or county, the possible shift in pulpwood away from current users to biomass is limited to 20% of pulpwood supply, which is reported in 2007 Forest Service TPO database (USDA Forest Service, 2007a). An analysis was conducted to determine the sensitivity to this limit. When the allowable shift from the pulpwood supply is increased to 30% of the 2006 pulpwood supply, the available biomass only increases a few percent at the \$90 per dry ton price and only up 9% above \$120 per dry ton when the allowable biomass is increased to 30% of the pulpwood supply.

The limitation on shifting of current pulpwood use to 20% was imposed on the recognition that the price elasticity estimate was based on currently available data with a certain variation over time. If prices change substantially, it is possible that demand elasticity could increase, which would cause the pulpwood supply to remain with current users and not be used for biomass. Rather than assume continuing steady shifting in response to increasing prices, a conservative assumption was made to limit the shifting of pulpwood supply from current users to biomass users at the 20% level.

3.6.2 Estimated Conventionally Sourced Wood

Pulpwood supplied to make pulp and panel products was 4.4 billion cubic feet, or about 66 million dry tons, in 2006. As the price for wood fuel feedstock approaches the price for pulpwood in a locality, there will be additional acres harvested for pulpwood to be used for energy, and some of the pulpwood going to pulp or panel mills will be diverted to wood energy use.

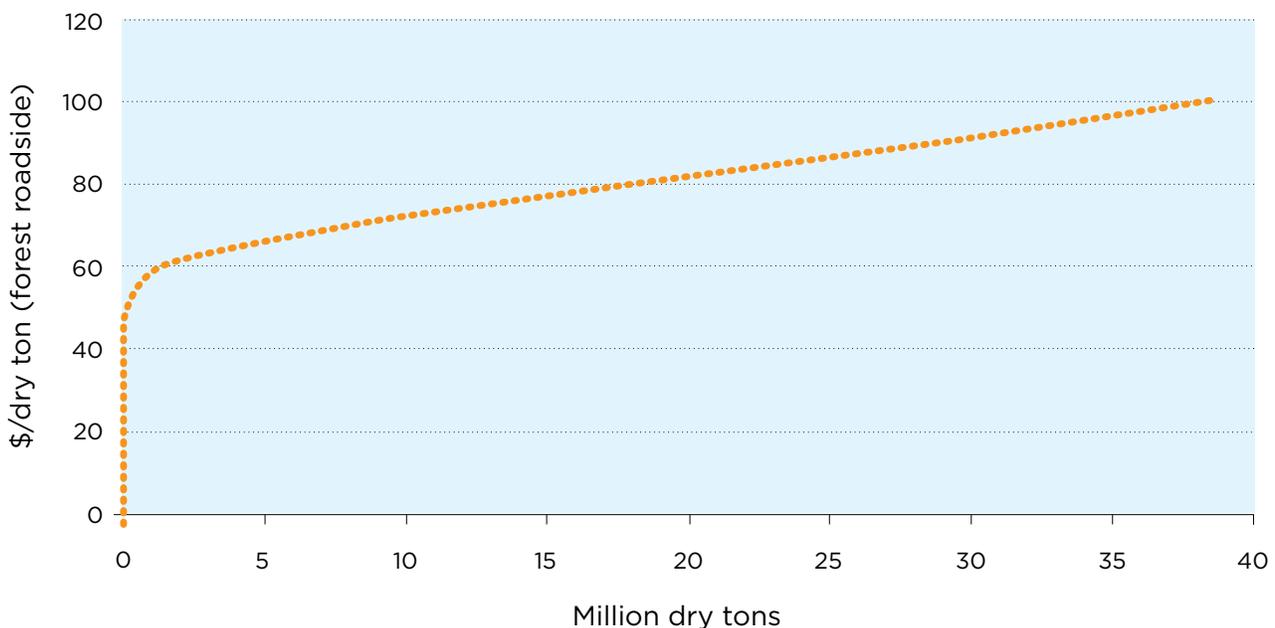
Supply curves (Figure 3.17) for pulpwood-sized roundwood at the county level were developed in several steps using basic concepts about supply and demand curves for existing pulpwood markets for each major region—North, South, and West. In general, it was assumed that regional levels of pulpwood supply can be approximated for bioenergy by starting with recent stumpage prices (Table 3.2), and starting quantities supplied are taken to be equal to recent quantities harvested.

Pulpwood for bioenergy starts to be supplied at current pulpwood stumpage prices, and harvest costs increase as the price that buyers are willing to pay increases. Pulpwood can either come from additional harvesting operations that specifically harvest pulpwood for bioenergy (possibly more expensive than current integrated harvesting) or from a shift in pulpwood use from current users to bioenergy producers. In the first case, additional harvesting operations are analogous to movement along state-level pulpwood supply curves to obtain bioenergy pulpwood. In the second case, it is backward movement along the current pulpwood demand curve, indicating shifts from current pulpwood uses to bioenergy.

At \$60 per dry ton at roadside, the estimated pulpwood supply from additional harvest or shifts from current users is 1.4 million dry tons per year. At a roadside

price of \$80 per dry ton, the amount of pulpwood for use as biomass is 18 million dry tons per year; from that total, 13 million tons is the main stem of trees, or a 20% increase over the 2006 harvest level of 66 million dry tons. Such an increased amount would be provided with a stumpage price increase of about 26%.³⁰ The rest of the price increase is due to increased harvest costs needed to obtain additional pulpwood supply. Supply at \$100 per dry ton or less is 38.6 million dry tons annually, of which 29 million tons is from the main stem of the trees—a 44% increase. This increase would be generated by a stumpage price increase of about 58%. The estimated increases in pulpwood supply are fairly coarse and are particularly uncertain for higher levels of price increase, which are outside the range of prices used to estimate the supply and demand elasticities.

Figure 3.17 : Estimated supply of pulpwood for bioenergy annually



³⁰ It is assumed that percent change in pulpwood biomass supply is equal to $(0.34 + .42) \times$ percent change in stumpage price. The quantity includes both additional supply from new harvesting and supply from a shift of current pulpwood harvest away from current users to bioenergy users.

3.7 Total Supply of Forest Biomass and Wood Wastes

Table 3.3 provides a summary of the currently available biomass at a range of prices for the forest biomass and wood wastes feedstocks. There are estimates for the two major sources of forest biomass feedstocks: logging residues and thinnings (shown as a composite), which are based on an assumption of a 50:50 ratio as the transition from logging residues to integrated harvesting occurs. This avoids double counting for both residues and thinnings. At the highest price estimate shown in Table 3.3 of \$100 per dry ton, the available biomass from logging residues and thinnings as integrated composite operations is about 43 million dry tons annually. Even at a price of \$200 per dry ton (not shown in the table), the additional biomass is much less than 10 million dry tons per year. These levels already account for the biomass that is retained onsite for sustainability purposes. At a price of \$60 per dry ton, annual availability is estimated to be about 97 million dry tons. The thinnings portion of these numbers is for all land ownerships and includes federal lands, even though they do not currently qualify under the Renewable Fuels Standard. Removal of the federal lands has little effect on the total biomass availability, reducing the estimated total at the \$60 price by only 7 million dry tons. For conventional pulpwood to energy, the higher quantities have considerable uncertainty as

they are based only on a 50% change in the current base stumpage price. Volume estimates above \$80 per dry ton are outside the model parameters. Figure 3.18 depicts the estimated forestland cellulosic feedstocks by states at an example price of \$80 per dry ton.

Future estimates are shown in Table 3.4. Because the thinnings are already averaged across the next 30 years and there is limited data for many of the feedstocks, there is little estimated change over the next 20 years. Assuming a price of \$60 per dry ton, the total available tonnage only increases from 97 million dry tons per year in 2010 to 102 million dry tons per year in 2030. Using a forest roadside price of \$80 per dry ton, the total quantity of composite residues increases from 1.6 to 2.0 million dry tons for each year (depending on whether federal land is counted). Conventional pulpwood is fairly constant at the prices shown in the table over the time period. Only after prices are higher than \$60 per dry ton, conventionally sourced feedstocks start making significant contributions. All other residue quantities at \$80 per dry ton are the same as shown at \$60 per dry ton. There are no scenario changes with the forest biomass and wood wastes—only the baseline.

Figure 3.18 : Current state shares of available forest biomass resources at \$80 per dry ton or less



Table 3.3 Summary of Potential Forest Biomass and Wood Wastes (2012)

Feedstock (\$ per dry ton)	<\$20	<\$30	<\$40	<\$60	<\$80	<\$100
Million dry tons						
Other Removal Residue	4.4	12	12	12	12	12
Composite Operations	9.5	30	36	40	42	43
Without Federal Land	8.3	26	31	35	36	37
Treatment Thinnings, Other Forestland	0	0	0	3.2	6.4	6.4
Without Federal Land	0	0	0	1.8	3.6	3.6
Mill residue, unused primary	1.3	1.3	1.3	1.3	1.3	1.3
Mill residue, unused secondary	6.1	6.1	6.1	6.1	6.1	6.1
Urban Wood Waste – C & D	4.4	11	14	22	22	22
Urban Wood Waste – MSW	7.7	8.7	9.2	10	10	10
Conventional Pulpwood to Energy*	0	0	0	1.5	19	40
Total – All Land	33	70	79	97	119	142
<i>Total – Without Federal Land</i>	<i>32</i>	<i>66</i>	<i>75</i>	<i>90</i>	<i>111</i>	<i>133</i>

Notes: Does not include currently used biomass from Chapter 2. Totals may not add up correctly due to rounding

* Although shown here for convenience, the estimated conventional pulpwood used as bioenergy above \$80 per dry ton is outside the model parameters, which could result in significant errors.

Table 3.4 : Summary of Baseline Potential Forest Biomass and Wood Wastes at Selected Roadside Prices

Feedstock (\$ per dry ton)	40	50	60	40	50	60	40	50	60	40	50	60
	2012			2017			2022			2030		
Million dry tons												
Other Removal Residues	12	12	12	12	12	12	13	13	13	13	13	13
Conventional Pulpwood to Energy	0.0	0.1	1.5	0.0	0.1	1.6	0.0	0.1	1.8	0.0	0.1	1.9
Composite Operations	36	38	40	36	39	40	37	39	41	37	39	41
Without Federal Land	31	33	35	32	34	35	32	34	35	32	34	36
Treatment Thinnings, Other Forestland	0.0	0.0	3.2	0.0	0.0	3.2	0.0	0.0	3.2	0.0	0.0	3.2
Without Federal Land	0.0	0.0	1.8	0.0	0.0	1.8	0.0	0.0	1.8	0.0	0.0	1.8
Mill residue, unused secondary	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1
Mill residue, unused primary	1.3	1.3	1.3	1.3	1.3	1.3	1.4	1.4	1.4	1.4	1.4	1.4
Urban Wood Waste – C & D	14	22	22	15	23	23	15	23	23	16	25	25
Urban Wood Waste – MSW	9.2	10	10	9.5	10	10	10	11	11	10	11	11
Total – All Land	79	91	97	81	92	98	82	93	100	83	95	102
<i>Total – Without Federal Land</i>	<i>75</i>	<i>86</i>	<i>90</i>	<i>76</i>	<i>87</i>	<i>92</i>	<i>77</i>	<i>88</i>	<i>93</i>	<i>79</i>	<i>90</i>	<i>95</i>

3.8 Summary

Although a significant amount of effort went into the analysis, the estimates are still only as good as the underlying data and dependent on the underlying assumptions. This concern is further compounded when developing comprehensive cost estimates at county levels. The FIA database brings significant amounts of data to the analyses. However, there are limitations concerning its use for biomass since the primary FIA focus is on merchantable inventory. The use of the data and some of the issues associated with using FIA data at the county level are discussed.

There is very little data on stumpage prices for biomass, and the extrapolation of the available data has limitations. This is especially true when estimating the availability of conventionally sourced biomass, which has high uncertainty at higher prices. Furthermore, the model is developed from historical supply/demand elasticity parameters that may or may not be representative of future market dynamics. There is very little data on biomass harvest systems tailored for handling logging residues, small stems, or integrated production. The largest gap in data is post-consumer wood residues. Limited data are available for C&D wood, and there are large voids for the amounts and costs for recovery of urban wood.

The underlying assumptions are based on the best available information and grounded in the expertise of the authors. The biomass estimates can readily change with them. The primary example is the development of the supply curves. Another considerable example is

the recovery of logging residues—whether they will be collected after the original harvest or as part of that harvest. The speculation is that integrated systems will be used to recover residues because of costs. As a last point on assumptions, the use of biomass retention is a primary concern for long-term site productivity and a surrogate for other sustainability criteria, such as habitat. Retention alone, not assuming the use of BMPs and assuming that removals do not exceed growth, does not truly represent the full measure of sustainability. Other considerations are needed. To aid the readers with interpreting the results, they will have access to the KDF for additional analyses using various assumptions.

Finally, the development of this chapter pointed to several needs, as summarized below:

- Improving the biomass portions of the FIA database
- Understanding and modeling the long-term effects of biomass removal under a range of soil, climate, and management schemes
- Improving the databases (e.g., mill residues, urban wastes, and costs)
- Developing and integrating biological and economic models for sustainability assessments.



U.S. BILLI N-TON UPDATE

Biomass Supply for a Bioenergy and Bioproducts Industry



August 2011

U.S. Billion-Ton Update:

Biomass Supply for a Bioenergy and Bioproducts Industry

A Study Sponsored by
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