

CHAPTER 9:

Biomass Supply

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Biomass feedstock for biochar production consists of three major categories: *agricultural biomass* (e.g., orchards or vineyard prunings, straw, corn stover, manure), *woody materials from urban refuse disposal* (e.g., clean woody construction debris, yard waste, materials from urban vegetation management; referred to in this report as *urban woody biomass*), and *woody materials from vegetation or forest management outside of urban areas* (e.g., forest harvest, wild fire fuel reduction, forest restoration, recreation maintenance; referred to in this report as *forestry biomass*)¹. In some parts of the Pacific Northwest (PNW), agricultural residues are abundant, and urban woody residues represent an opportunity to tap into a waste stream that already has centralized collection (further detailed in *Chapter 7: Biochar Produced and Utilized at Municipal Compost Facilities*). While forestry biomass represents the largest potential waste stream from which biochar may be sourced, it is widely dispersed and must include assumptions that harvest operations occur in a sustainable manner in line with forest management objectives.

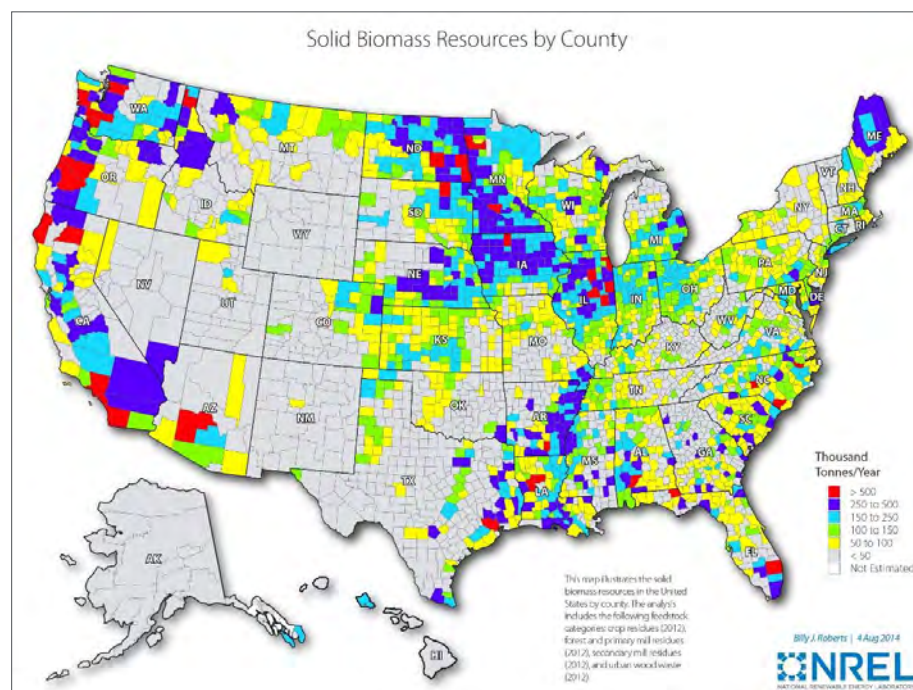


Figure 9.1. A 2014 map of solid biomass resources by county across the United States including crop residues, forest and mill residues, secondary residues, and urban wood waste. (NASEM 2019)

A summary of environmental, policy and regulatory considerations related to forestry biomass harvest is provided in Skog & Stanturf (2011).

Previous studies of biomass availability meant to inform bioenergy production can provide valuable information on feedstock for biochar. Numerous studies of

both quantity and potential uses of forest harvest operations that create low- and no-value woody biomass have been conducted over the past 15 years. The PNW and western U.S. regions are relatively rich in biomass resources, offering potential for sustainable biomass harvesting that can provide feedstock for biochar production (Figure 9.1).

¹ For detailed information on characteristics of biomass feedstocks and impact on the resulting biochar, see Chapter 3 of Lehmann & Joseph (2015).

In this chapter, we review results from state estimates of biomass for Washington, Oregon, and California. Next, we review biomass supply assessments of the PNW, the western U.S., and the U.S. as a whole.

STATE ESTIMATES

Washington

Solid waste generally contains large quantities of organic materials (about 40%) that are easily decomposable (Figure 9.2; Ecology 2016). A large portion of the diverted organics are food and green waste (lawn and yard trimmings, leaves), and about 12% is woody biomass. The woody biomass includes such materials as trimmings from bushes and trees, clean lumber, pallets, crates, and trees from land clearing. These, combined with food and green organics, are the main sources of composted materials.

Solid waste in Washington has been sampled and characterized, most recently in 2015-2016 (Ecology 2016). The amount of clean wood (non-treated or painted, lumber, pallets, engineered, and natural wood) disposed was 193,375 tons, or 9.6% of waste disposed (Table 9.1).

Jensen & Moller (2018) used a broader general estimation method based on national data as another approach for estimating urban woody materials in the waste stream. They applied national data on waste generation based on population size; estimates were based on a detailed accounting for a particular county (Spokane County) and results extrapolated to the Washington State level (Table 9.2).

Jensen & Moller (2018) also estimated woody materials by using business types responsible for the most generation of woody materials by applying a common factor for material generation either on a per business or a per employee basis. Specifically, they estimated woody materials from land-clearing in Spokane County to be 180,000 tons per year, based on 180 landscaping services businesses with 892 employees (U.S. Census Bureau), and an estimate that tree

trimming and landscaping companies generate about 1,000 tons per crew per business per year (Wiltsee 1998). This method may overlap with the yard debris categories in estimates of MSW disposed or recycled.

A 2008 estimate of potential biomass resources in Washington State estimated that forestry residues

Table 9.1. Washington Waste Composition Study (statewide results collected over one year period, June 2015- May 2016; modified from Ecology 2016).

Wood categories ¹	Percent	Tons
Yard & garden waste – pruning(s)	0.3%	6,389
Dimensional lumber	2.4%	48,955
Engineered wood	3.4%	68,778
Pallets & crates	3.0%	59,712
Other untreated wood	0.2%	3,873
Wood by-products	0.2%	4,563
Natural wood	0.1%	1,104
Total clean wood disposed	9.6%	193,375
WA statewide waste stream disposed	100%	2,007,171

¹ Defined in Ecology (2016)

Table 9.2. Estimated total tons of woody fractions in Spokane County, Washington based on Moller (2009) study methods.

Material type (woody fraction)	Spokane County, Estimated (tons/yr) ¹	WA State (tons/yr) ⁵
Municipal Solid Waste (MSW)	22,829 - 38,048 ²	334,000 - 557,000
Land Clearing Debris	180,000 ³	1,800,000 ⁶
Construction and Demolition	44,185 ⁴	647,000
Total	247,014 - 262,233	2.8 M - 3.0 M

¹ Calculations based on 2015 Spokane County population data (Tweedy 2016)

² Based on 1.55 tons MSW per capita per year (Moller 2009), woody fraction is 3 to 5% of the MSW stream (Wiltsee 1998)

³ Based on 0.12 dry tons of urban wood waste per person per year (Wiltsee 1998)

⁴ Based on 0.09 tons per capita per year (Moller 2009), 2015 Spokane County population data (Tweedy 2016)

⁵ Population proportioned to statewide based on per capita equivalent 14.6

⁶ Assuming ten counties at Spokane County rate

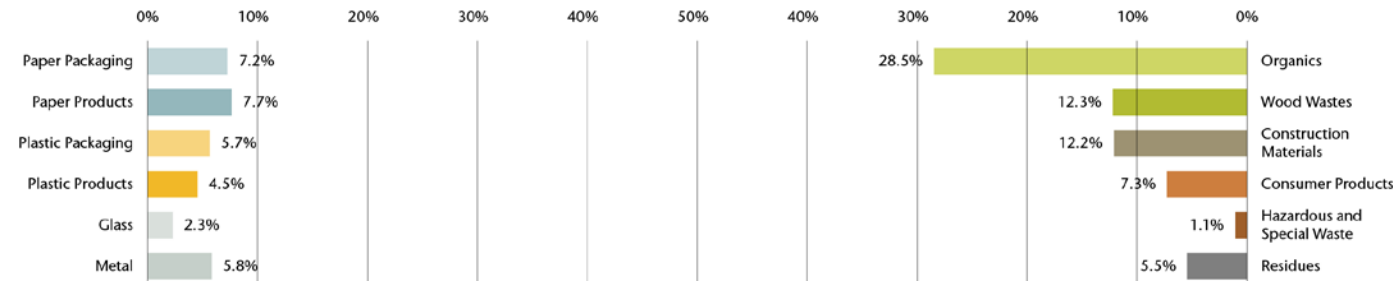


Figure 9.2. Overall Washington statewide disposed waste stream composition by material class, 2015-2016. (Adapted from Ecology 2016)

could provide 11.3 million dry tons per year of potential biomass, or 66% of the total estimated biomass available in the state (Frear 2008; Figure 9.3).

Washington State University researchers completed a Biomass Inventory and Bioenergy Assessment with support from the Washington State Department of Ecology. This study evaluated 42 types of waste across seven waste categories (field residue, animal waste, forestry, food packing, food processing, animal processing, and municipal organics) in each of the 39 counties in Washington (Ecology 2005; updated in Ecology 2011). Forest materials inventoried (logging residues, forest thinnings, mill residues, land clearing, and orchard debris) represented 5.8 million bone dry (BD) tons out of the total 10.6 million BD tons or 55% of inventoried biomass. These low-value biomass sources are typically composted, ground for hog fuel, burned onsite, or left in place. Forestry biomass totals and bioenergy potentials by county are shown in Figure 9.4.

The Washington Forest Biomass Supply Assessment estimated contributions of forest-based biomass as a byproduct of sustainable forest operations (Perez-Garcia et al. 2012, p.12). The model and data for available biomass presented in this report varies dramatically from estimates by other sources but is somewhat consistent with Cook & O’Laughlin’s (2011) estimate of forest biomass supply for Washington at 1.2 and 1.6 million BD tons annually at \$10 and \$40 per BD ton, respectively. There are many qualifiers in this report that may explain low biomass assessments. For example, waste biomass left on harvested sites was estimated at 8 and 11 million BD tons per year in 2010 and 2015, respectively, apparently to reflect that much of the biomass is not yarded for recovery and use because it is too expensive to transport.

Washington’s woody biomass from municipal wastes, forests, and agriculture was evaluated in a recently completed study by Amonette (2021). The work reviews the biomass supply Washington counties

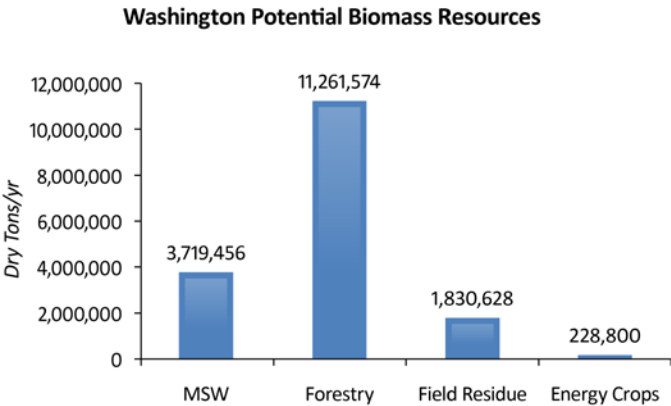


Figure 9.3. Estimate of Washington’s potential biomass resources. (Frear 2008)

chosen for proximity of the wildland urban interface, fire risk, and the production of municipal solid waste, forest biomass, and agricultural crops. Amonette (2021) estimated available annual biomass totals of 8.7-25.4 green million metric tonnes (Table 9.3). The dominant biomass source is forestry residuals (aggressive & conservative harvest scenarios; approximately 73-91%, depending on scenario). The most promising opportunities exist where the wildland urban interface is in close proximity to agricultural land.

Biomass supply data can be combined with an assessment of the potential for soil carbon storage using biochar. Amonette (2021) focused on estimating the potential for atmospheric carbon drawdown by using biochar created from forestry residues and wood considered as “waste” that have historically been burned in slash piles because they have little economic value and includes spatial integration of soil productivity and crop information at 1 hectare resolution, separate accounting for changes (positive or negative) in soil organic carbon that results from feedstock harvesting and/or biochar application, and tracking biochar production and soil storage capacities over time. Washington’s 100-year capacity for biochar production is estimated to be 140-380 million metric

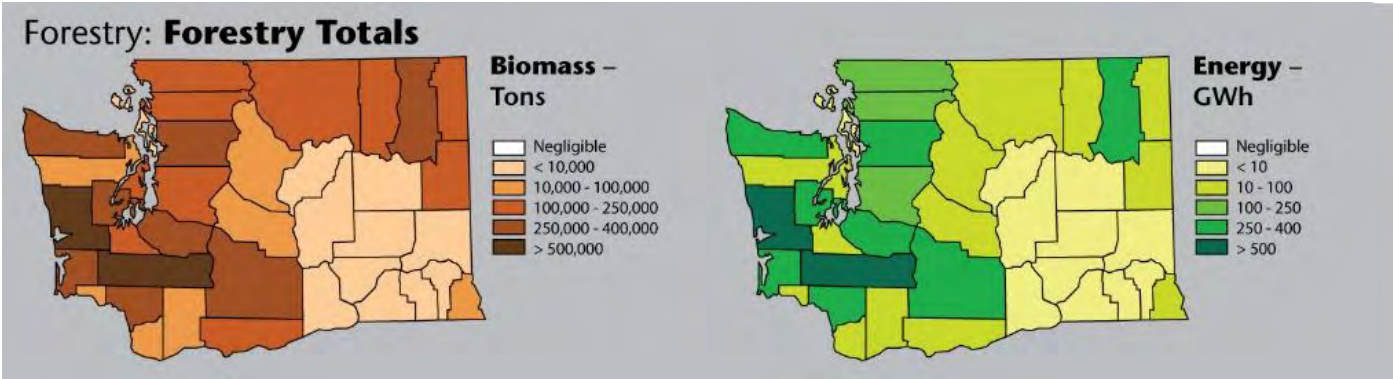


Figure 9.4. Washington State annual forestry biomass totals and energy potential by county. (Ecology 2011)

tonnes carbon, for eight scenarios including crop residue, MSW, and forestry residue feedstock streams. These would result in a 100-year climate offset of approximately 640-1,600 million metric tonnes carbon dioxide equivalent (CO₂e) and an ultimate drawdown of 38-93 parts per billion by volume of atmospheric CO₂e. At the maximum biomass-utilization rate, which is achieved after five decades, biochar production could offset between 9% and 20% of the greenhouse-gas emissions in Washington State (taken at 2018 levels). Under current storage

Table 9.3. Annual biomass estimates for Washington State’s 39 counties. (modified from Amonette 2021)

Source	Biomass	
	1,000 green tons ¹	1,000 green tonnes ¹
MSW greenwaste ²	47	43
MSW recovered wood ³	343	311
MSW total	390	354
Harvested crop residues	2,230	2,020
Timber harvest scenario (conservative – landing only)	7,010	6,360
Timber harvest scenario (aggressive – landing and central facility)	25,300	23,000
Totals with conservative – landing only	9,630	8,730
Totals with aggressive – landing and central facility	28,000	25,400

¹ 50% moisture content is common for forestry biomass, but moisture levels can vary considerably. For example, wood that has been sitting in a slash pile for the summer can have much less moisture (18-25%).
² Greenwaste is defined as yard & garden waste—prunings from a survey conducted in 2015-2016 and reported on the basis of 2014 tonnage rates by the Washington State Department of Ecology.
³ Recovered wood waste is dimensional lumber, engineered wood, pallets & crates, other untreated wood, and natural wood from a survey conducted in 2015-2016 and reported on the basis of 2014 tonnage rates by the Washington State Department of Ecology.

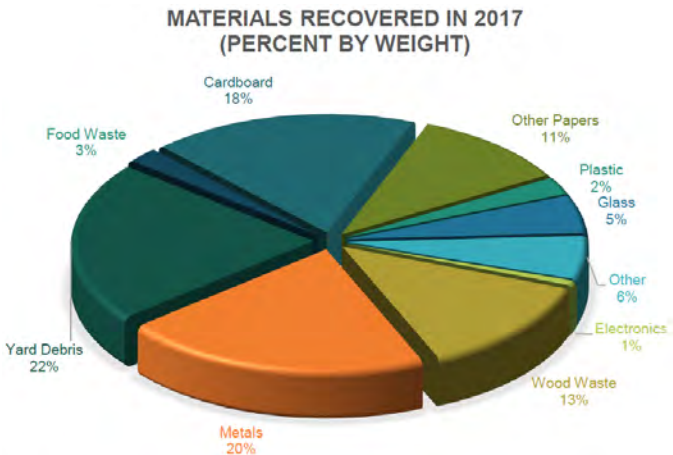


Figure 9.5. Oregon material recovery in 2017. (ODEQ 2017)

potential assumptions, the biochar-carbon soil-storage capacity will be saturated in 62 to 106 years for the full scenarios that include crop residues, MSW, and timber-harvest biomass residues, however this limitation could be addressed through the development of additional storage reservoirs and technologies.

Oregon

In Oregon, the amount of clean wood biomass disposed in 2016 was 218,572 tons, representing 7.7% of waste disposed (Table 9.4; ODEQ 2016).

While no breakdown of the composition of compost feedstocks is possible in Oregon, the Oregon Department of Environmental Quality (ODEQ) produces a Materials Recovery report for recycled and recovered wastes (Figure 9.5). Nearly 300,000 tons of woody biomass are recovered from the waste stream annually for compost and energy use (Figure 9.6).

Table 9.4. Oregon Waste Composition Study. (statewide results for 2016; modified from ODEQ 2016)

Wood categories ¹	% of Total Waste	Clean Tons
Small prunings under 2 inches	0.40%	11,975
Large prunings over 2 inches	0.18%	5,627
Reusable lumber: unpainted	1.00%	30,742
Clean sawn lumber	2.85%	73,052
Clean engineered wood	1.53%	45,188
Cedar shakes and shingles	0.27%	6,925
Wood pallets and crates	1.47%	45,062
Total clean wood disposed	7.70%	218,572
OR statewide all sub-streams	100%	3,060,520

¹ Defined in ODEQ (2016)

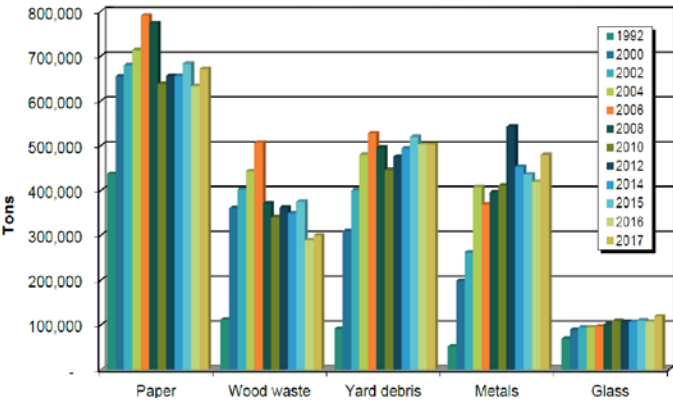


Figure 9.6. Oregon wood and other materials recovered from waste stream 1992-2017. (ODEQ 2017)

In a 2006 report for the Oregon Forest Resources Institute (OFRI), authors estimated potential biomass supply from fuel reduction treatments across 20 eastern and southern Oregon counties in the dry, inland forest region of Oregon (OFRI 2006). Key findings of this report were that 4.25 million acres (about 15% of Oregon's forestland) have the potential to provide forest biomass by thinning forest stands to reduce risk of uncharacteristic wildfire. Thinning these acres over 20 years could produce 1.0 million BD tons per year of woody biomass, not including merchantable sawtimber. It would cost an average of \$59 per BD ton to deliver this biomass to processing facilities based on integrated harvesting and collecting which combines costs associated with biomass with the costs associated with merchantable timber. Costs for woody biomass would be much higher if only non-merchantable material is harvested.

California

In 2015, a group led by Katharine Mitchell (University of California Davis) used the Biomass Summarization Model (BioSum), a temporally dynamic, spatially explicit, forest stand development model, to estimate woody biomass for biofuel that could result from forest operations. In California, 7 million BD tons of woody residues would be available for the next 40 years (Mitchell et al. 2015).

In an assessment of biomass resources in California, Williams et al. (2015) found that although biomass in the state totals 78 million gross BD tons per year, biomass considered to be available on a sustainable basis is estimated to be 35 million BD tons per year. Of the gross resource, 25 million tons are from agriculture, 27 million from forest resources, and 26 million tons from municipal wastes, exclusive of waste in place in landfills and biomass in sewage. The current technical potential includes more than 12 million BD tons per year in agriculture, 14 million BD tons per year in forestry, and 9 million BD tons per year in municipal wastes.

REGIONAL AND NATIONAL BIOMASS SUPPLY ASSESSMENTS

In response to interest in creating renewable fuels, limiting fossil-based carbon emissions, reducing occurrences of catastrophic forest fires, improving forest health, and carbon sequestration, several organizations have conducted western regional biomass supply assessments focused largely on woody biomass from forests and including municipal and industry resources. The most relevant of these efforts are described below.

Forest Biomass Supply Analysis for Western States

In an assessment completed for the Western Governors' Association (Cook & O'Laughlin 2011), estimates were made of forest biomass at different roadside (forest material available on log landings near roads) price points. Forest biomass includes forest thinnings (small-diameter trees or brush removed to reduce hazardous fuels and/or improve forest health conditions), forest residues (logging slash), and mill residues. Washington and Oregon forest biomass supply ranges from 2.5 million dry tons at \$10 per ton roadside price to 3.25 million dry tons at \$40 per ton roadside price with roughly equivalent biomass contributed from each state (Table 9.5). In addition, five states have the greatest amounts of available forest biomass: California, Oregon, Washington, Montana, and Idaho. County-level tables for individual states are available separately.

Northwest Advanced Renewables Alliance

In 2016, the Northwest Advanced Renewables Alliance (NARA) project completed an assessment of available woody biomass created from timber harvesting, prescriptive forest thinnings, and mill residues that could be gathered and converted to jet fuel. The area for this assessment included Oregon, Washington, Idaho, and Montana. Logging residues averaged a total of about 14 million green tons annually for Oregon and Washington combined from 2002 through 2014, while residues in Idaho and Montana each averaged less than 2 million green tons annually (Figure 9.7; Berg et al. 2016, p. 21).

2005, 2011, and 2016 Billion Ton Reports

In 2005, Perlack et al. sought to answer the question: Could the U.S. produce a sustainable supply of biomass that could displace at least 30% of the nation's petroleum consumption? This study, which became known as the Billion Ton Report said 'yes!' However, the amount of potential biomass available was then revised to 137 million dry tons. If recent production increases from forest operations were considered, then the biomass potential could be 225 million dry tons. In 2011 an updated Billion Ton Report (USDOE 2011) noted that the potential forest biomass and wood waste available at \$40 per dry ton would be about 79 million dry tons. This number is less than the 2005 estimate because of the change in pulpwood and sawlog markets.

Table 9.5. Western states forest biomass supply availability in dry tons. (Cook & O’Laughlin 2011)

State	Roadside price per ton						
	\$10	\$15	\$20	\$25	\$30	\$35	\$40
AZ	75,829	145,672	170,010	222,846	230,036	231,423	231,601
CA	1,904,370	2,733,657	3,155,708	3,425,863	3,538,764	3,569,309	3,602,018
CO	100,120	123,366	197,806	228,948	274,847	300,161	312,104
ID	796,410	853,887	992,527	1,208,995	1,338,801	1,395,282	1,429,463
KS	8,720	8,720	8,720	8,720	8,720	8,720	8,720
MT	646,769	720,152	1,030,913	1,272,212	1,417,237	1,477,018	1,533,464
NE	4,971	4,971	4,971	4,971	4,971	4,971	4,971
NV	4,799	7,791	7,791	7,871	7,871	7,943	7,943
NM	78,314	90,450	143,710	213,109	279,713	292,336	301,716
ND	265	265	265	265	265	265	265
OR	1,339,728	1,466,478	1,541,285	1,585,410	1,611,490	1,618,589	1,648,377
SD	95,407	95,407	97,729	103,466	108,020	108,020	108,020
TX	3,022	3,022	3,022	3,022	3,022	3,022	3,022
UT	37,927	42,887	50,736	77,294	98,360	104,654	116,094
WA	1,152,105	1,274,302	1,360,558	1,467,007	1,517,302	1,550,350	1,606,562
WY	83,644	105,728	126,208	156,919	183,664	196,388	1,971,717
Total	6,332,399	7,685,757	8,891,960	9,986,918	10,623,082	10,868,450	11,111,511

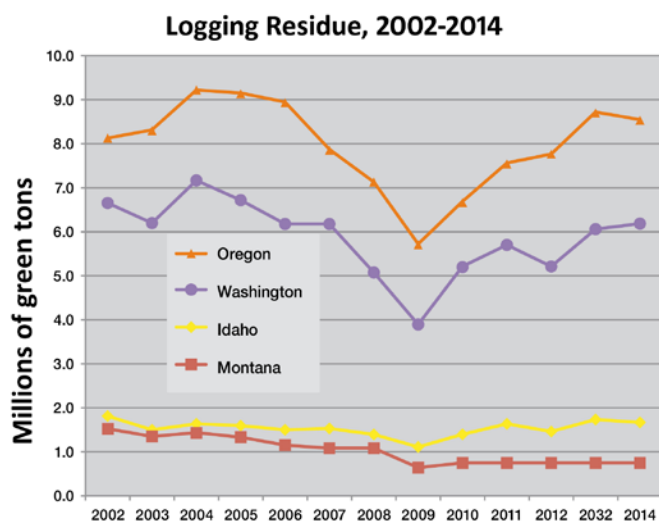


Figure 9.7. Annual logging residue quantities from Idaho, Montana, Oregon, and Washington including bole wood, tops, and limbs 2002-2014. (Berg et al. 2016, p. 21)

According to the 2016 Billion Ton Report (USDOE 2016), in Washington, Oregon, California, Montana, and Idaho there is an estimated 8.3 million dry tons of logging residues available annually at \$80 per dry ton. This estimate is expected to stay the same or increase slightly until 2050, particularly in Oregon and Washington. In all five western states with sizeable portions of logging residues it may be possible to collect logging residues at both conventional logging

Table 9.6. Estimated forest-based biomass supply from different sources.

	Available material Billion Ton Report (MODT ¹ in U.S.) ²	Available material BRDI ² (2008) report (MODT)	Available material (MODT in OR, WA, ID, CA) ³
Integrated harvesting			
Logging residue	47	20	1-3
“Other” removal residues	17	6	1.8
Mill residues	n/a	15	6.8
Urban residues	47	3	n/a
Conventionally sourced wood (e.g., pulpwood)	74	4	1-6
Total	185	48	100% of area treated

¹ MODT = million oven dry tons

² Data from Skog & Stanturf 2011

³ Data from Wear et al. 2013

sites and, from thinning operations, thereby reducing fire hazard and insect and disease outbreaks.

Biomass Research and Development Initiative

An analysis commissioned by the U.S. Federal Biomass Research and Development Initiative (BRDI 2008)

suggested that at \$44 per oven dry ton² (ODT), about 48 million ODT of forest-based biomass would be available in the U.S. (Table 9.6). This analysis assumed that all forest-based and agricultural biomass would be available for biofuels. However, this material could be used for increased electric power, heat energy, or biochar production. This estimate from the BRDI report is lower than the Billion Ton Report estimate because it assumes that thinning operations would integrate harvest operations where sawlogs/pulpwood are harvested along with other biomass. Thinning operations are often limited by the demand for sawlogs and pulpwood in each region.

Additional Considerations for Forestry Biomass

It should be noted that gross biomass estimates do not account for the need for some amount of biomass to remain in forest and agricultural systems. For example, it has long been known that coarse and fine woody biomass, needles, and leaves are critical to ecosystem function and nutrient cycling, but that the amounts and turnover times vary by ecosystem. Therefore, only a portion of the residues would be used for biochar production and, where needed, a portion of the biochar would be added back to the forest soil to maintain or increase soil carbon.

Much of the low- and no-value woody biomass created from harvest operations are currently burned in slash piles or using broadcast burns. This practice wastes energy, creates smoke, and releases particulates into the air. Further, pile burning can produce an extreme heat pulse into the soil, which results in loss of soil organic matter, microbial population shifts, dead plant roots and seeds, and alteration of soil acidity, nitrogen, and physical properties. The scars left from pile burning often results in long-lived openings that have enhanced establishment of invasive or non-native plant species, but usually not native shrubs or trees (Rhoades & Fornwalt 2015).

CONCLUSIONS

Each of the inventory methods indicates that there is an abundance of woody biomass that can be sustainably harvested, converted to biochar, and applied on many different kinds of sites and soils. Conversion of woody biomass to biochar enhances the value of residues that are now considered “waste.”

Key points are:

- Though municipal waste stream and agricultural residue resources are small relative to forestry residues, clean woody biomass in the solid waste stream is not well sorted and represent an opportunity to separate these resources for further conversion to biochar.
- Most woody biomass resources are from forest harvest operations. Different harvest, transport, and pricing scenarios affect the assessment of available biomass. For example, whole tree yarding and biomass collection on the landing would make gathering costs more reasonable than harvest operations that leave residues scattered across the harvest unit.
- Key limitations on forestry biomass collection depend on the specific analysis, but often include the cost of harvest, processing and transport, limitations on the amount of residue produced due to the need for coproduction of sawlogs or pulpwood, spatial distribution of biomass in relation to processing facility, and the need for and biological limits on forest health thinnings (Skog & Stanturf 2011).

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2 Bone dry (BD) ton and oven dry ton (ODT) are both terms that imply biomass at 0% moisture, so are essentially interchangeable.

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