6. FACILITY SITING ANALYSIS

This section describes the process used to identify, screen and rank potential conversion sites in the study area. The sites identified within each county were screened for appropriateness as potential conversion sites, and then sites were ranked to identify one potential candidate site within each county. In each county, there were multiple sites that could be suitable, and the differences between some sites are minimal. Consideration should be given to alternative sites should a detailed engineering evaluation be conducted in the future.

6.1 Site Identification and Preliminary Screening

The site identification effort identified 37 potential locations (see Appendix D). While there certainly are other suitable sites in the three counties, these were the most readily identified without a detailed examination of parcel databases or aerial photography. Identifying sites involved collecting information on existing industrial sites and candidate new sites that could accommodate biomass power or liquid fuel manufacturing. Data sources for industrial sites included the Oregon Department of Environmental Quality (DEQ) and the U.S. Environmental Protection Agency (EPA) AirGraphics database. Specifically, the Oregon DEQ Facility Profiler is an online mapping application that allows users to identify facilities with existing state permits.[56] Oregon DEQ staff provided information on industrial boilers in the study area. The EPA Enviromapper Internet pages show sites with permits required under federal environmental laws. County planning and economic development agencies provided information on new industrial parks. Appendix E provides a list of all permitted boilers in the study area, provided by the Oregon Department of Environmental Quality. Boise Cascade currently has large wood boilers, and Johnson Lumber has smaller wood boilers, but neither currently generates power.

We conducted a preliminary screening to narrow the number of candidate sites. Criteria for this initial screening included sites with total land acreage less than five acres (a 5-MW facility can be sited on approximately five acres), sites located in cities or towns that would interfere with existing land uses (e.g., residential or commercial) and sites located next to airports. The first criterion was meant to eliminate sites that are not large enough to accommodate a biomass power or ethanol manufacturing facility. The second and third criteria eliminated sites that are likely to be subject to stringent zoning conditions and resident opposition.

Table 6-1 provides the results of this initial screening.

[56] Oregon Department of Environmental Quality, *Facility Profiler 2.0* (http://deq12.deq.state.or.us/fp20/startpage.aspx).

Table 6-1. Top candidate sites for power or fuels manufacturing

Site name	County	Location	Existing land use
Elkhorn View Industrial Park	Baker	Baker City	Mostly industrial - little residential nearby
Ellingson Lumber main	Baker	Baker City	Industrial - closed sawmill (1997)
Ellingson Lumber S. Baker	Baker	Baker City	Closed particle board mill
Ellingson Halfway	Baker	Halfway	Former mill site
Far Site Concrete	Baker	Baker City	Sand/gravel pit - Primarily agricultural land use
Triple C Redi Mix	Baker	Baker City	Sand/gravel pit - Primarily agricultural land use
Boise - La Grande	Union	La Grande	Large sawmill
Boise - Elgin	Union	Elgin	Stud mill, Veneer/Plywood mill
Boise - Island City	Union	La Grande	Particle board mill, neighbors Baum Industrial Park, Borden Chemical
Baum Industrial Park	Union	La Grande	Industrial Park, neighbors Boise - Island City (particle Board plant), Borden Chemical
Union Industrial Park	Union	Union	Closed sawmill site. Next to agricultural experiment station
Elgin Industrial Park	Union	Elgin	Adjacent parcel to Boise - Elgin (stud mill, plywood mill)
Gelmekern Industrial Park	Union	La Grande	Industrial park - Primarily agricultural land use
Joseph mill site	Wallowa	Joseph	Former mill site
Bates mill site	Wallowa	Wallowa	Former mill site

6.2 Site Ranking

The sites listed in Table 6-1 were assessed for viability using the criteria in Table 6-2.

Table 6-2. Criteria used to rank potential conversion sites

Criterion	Score	
	Ethanol	Power
1) Miles to substation		
> five miles	1	1
One to five miles	2	2
< one mile	3	3
2) Zoning and existing land use		
Residential nearby	0	0
Undeveloped	1	1
Industrial	3	3
3) Combined heat and power (CHP)		
No	0	0
Possible	2	2
4) Likelihood of siting at location		
Never	Showstopper	Showstopper
Difficult	1	1
Moderate	2	2
Straightforward	3	3
5) Rail access		
Now	3	0
Could be developed	2	0
Not likely	Showstopper	0

The sites with the highest overall score were chosen for further evaluation. Information on each of these criteria was collected from site visits conducted in May 2003. Distance to a substation was determined either visually or, if a substation was not evident, by determining where substations were located on maps relative to the location. Zoning was determined by talking to landowners and county planners during the site visit. This criterion is somewhat subjective, because it takes into account proximity to residential and commercial areas and a sense of whether the site is likely to encounter problems because of inconsistency with surrounding land uses. Sites that were already industrial received higher scores for this criterion.

The potential for combined heat and power (CHP) was determined by evaluating whether there were obvious high heating loads such as major industrial uses near the land parcel. The likelihood of siting a facility at a particular location was in part subjective, but took into account values such as proximity to scenic byways or other natural features and total lack of industrial or other infrastructure. Rail access is vital to an ethanol plant, but it is not required for a power plant. Therefore, this criterion was used only for scoring sites for potential ethanol plants.

Table 6-3 provides the results of this scoring effort. The top sites within each county are very close in score. In Baker County, the Ellingson Lumber site in Baker City and the one in S. Baker City are both very similar in siting potential to the Elkhorn View Industrial Park. The differences are that the Elkhorn View site is largely undeveloped and is farther from residential areas, and thus may have fewer development issues. However, the Ellingson sites are owned and maintained by a motivated manager with experience in the industry. This could make these sites viable as well.

In Union County, all of the Boise Cascade facilities are potential sites due to existing land use, interested management and on-site heating loads. The Baum Industrial Park is adjacent to the Boise Cascade particleboard plant and a Borden chemical facility that produces adhesives. Because a cellulose ethanol plant developer has purchased the Baum site, it was the highest scoring site. However, a cogeneration facility or ethanol plant could also be sited at Boise Cascade facilities adjacent to or near the Baum site. The close proximity of the top sites within Baker and Union Counties makes the resource and technology assessment results applicable to any of the sites.

In Wallowa County, the Joseph mill site does not have access to municipal wastewater treatment, which makes it less desirable than the Bates mill site.

Table 6-3. Results of site scoring

Site	Location	Rail access (ethanol only)	Zoning / Existing Land Use	CHP	Siting Potential	Miles to Substation	Ethanol total	Power total
Baker County								
Elkhorn View Industrial Park	Baker City	2	3	0	3	2	**10**	**8**
Ellingson Lumber main	Baker City	3	2	0	2	3	**10**	**7**
Ellingson Lumber S. Baker	Baker City	3	3	0	2	2	**10**	**7**
Ellingson Halfway	Baker City	Showstopper	2	0	1	3	**0**	**6**
Far Site Concrete	Baker City	Showstopper	3	0	1	2	**0**	**6**
Triple C Redi Mix	Baker City	Showstopper	3	0	1	2	**0**	**6**
Union County								
Baum Industrial Park	Elgin	2	3	3	3	3	**14**	**12**
Boise - La Grande	La Grande	3	3	2	3	3	**14**	**11**
Boise - Elgin	Elgin	3	3	2	3	3	**14**	**11**
Boise - Island City	La Grande	3	3	2	3	3	**14**	**11**
Union Industrial Park	Union	2	1	0	1	3	**7**	**5**
Elgin Industrial Park	Elgin	3	3	0	2	3	**11**	**8**
Gelmekern Industrial Park	La Grande	0	1	0	2	3	**6**	**6**
Wallowa County								
Joseph mill site	Joseph	3	3	0	2	2	**10**	**7**
Bates mill site	Wallowa	3	3	0	3	2	**11**	**8**

Several sites that were not closely examined but have been the focus of interest by other parties include Eastern Oregon University, for which another cogeneration feasibility study was recently performed by Tritchka Engineering under contract to the Union County Economic Development Corporation.[57] This siting analysis was not intended to eliminate potential sites from consideration. Other suitable sites exist in the study area.

[57] Vernon Tritchka, Tritchka Engineering (personal communication with Tim Rooney, McNeil Technologies, Inc., May 14, 2003).

6.3 Detailed Descriptions of Candidate Sites

This section provides additional information about the sites selected to be the focus of the more detailed resource, technology and economic analysis for this study. Figure 6-1 shows the three candidate sites.

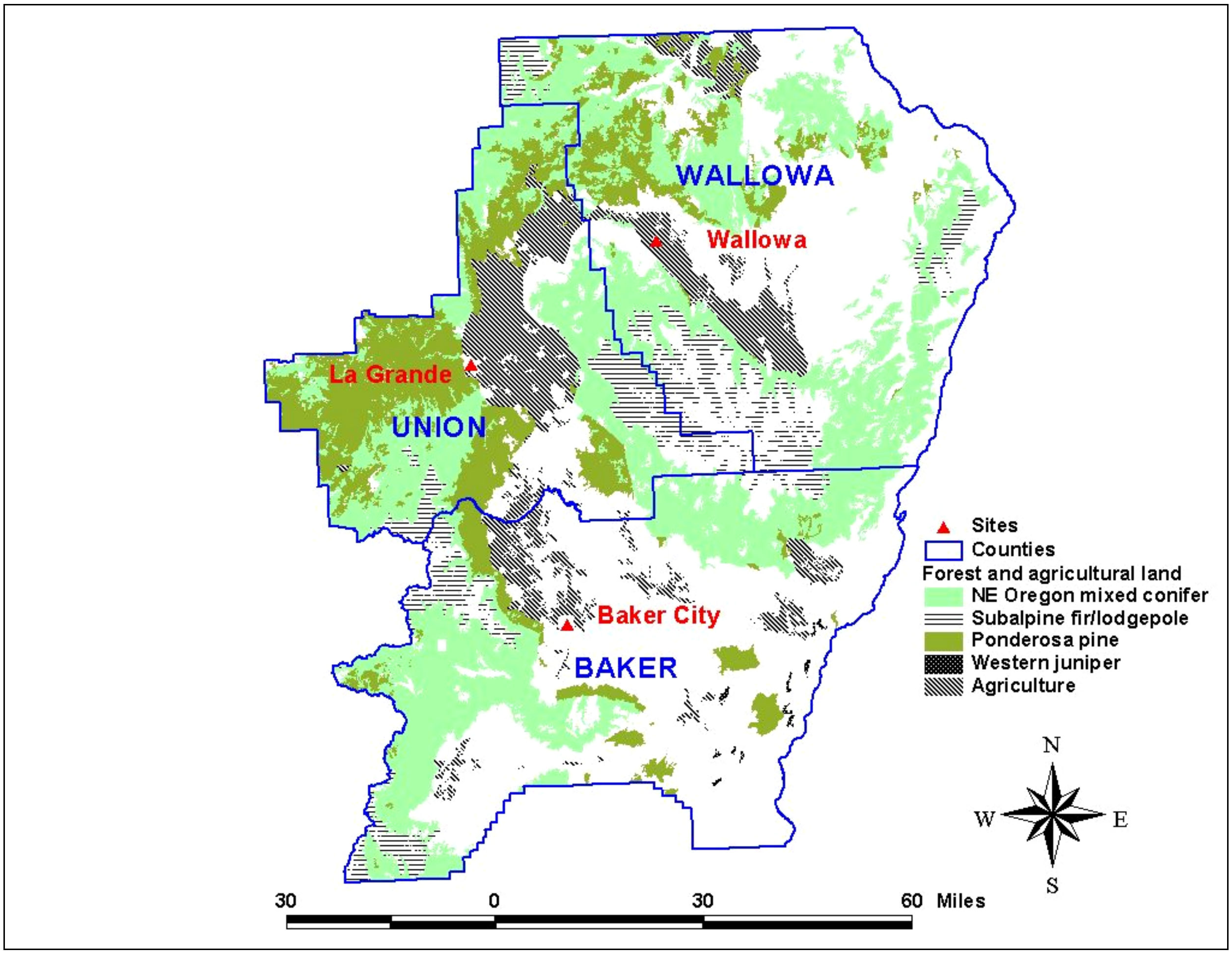

Figure 6-1. Candidate biomass facility conversion sites

6.3.1 Elkhorn View Industrial Park - Baker County

Elkhorn View Industrial Park (Figure 6-2) has a total area of 71 acres. Sewer, water, roads as well as electric, gas and telecommunications technology serve the site, which lies within Baker City's urban growth boundary or city limits. A Union Pacific rail line runs behind the property. The property is largely undeveloped. There is very little residential property nearby. The neighbors to the property include a metal fabrication company and, farther away, a hospital.

Figure 6-2. Elkhorn View Industrial Park, Baker City, Ore.

6.3.2 Baum Industrial Park - Union County:

Baum Industrial Park (Figure 6-3) is located four miles northeast of La Grande, Ore. Total acreage at the site is 80 acres. The site is zoned heavy industrial. Land is available for $14,000/acre. The site is located 2.5 miles from I-84.[58] The Baum site is adjacent to a Borden Chemical plant and a Boise Cascade particleboard processing facility. Sustainable Energy Development Inc. has purchased property at the Baum Industrial Site as a possible cellulose ethanol plant location.

Electricity is provided by Oregon Trail Electric Cooperative. Avista provides natural gas to the site. At the appropriate time, the site will be supplied by an 18-inch water line, with water provided by the City of La Grande. Water pressure fluctuates between 130 and 145 lb per square inch (psi).[59]

Photo courtesy of Union County Economic Development

Figure 6-3. Baum Industrial Park, La Grande, Ore.

[58] Union County Economic Development Corporation, *Industrial Sites,* La Grande, Oregon (http://www.ucedc.org/industrial.htm).
[59] Union County Economic Development Corporation, *Industrial Sites,* La Grande, Oregon (http://www.ucedc.org/industrial.htm).

6.3.3 Bates Mill Site - Wallowa County

The Bates Mill site (Figure 6-4) is a former sawmill location adjacent to wastewater treatment facilities and a rail line. There are ongoing efforts to redevelop portions of adjacent parcels into small scale forest products enterprises. The owner of the parcel is interested in investors who can redevelop the property into a viable business. Wallowa Resources is working with a number of parties to evaluate possible siting of firewood and post and pole manufacturing businesses on the property, which could complement a bioenergy facility at the site.

Figure 6-4. Former Bates mill site, Wallowa, Ore.

7. BIOMASS COST AND SUPPLY

This section presents the estimated supply of agricultural residue, wood products residue and forest residue in the study region. Biomass supply curves integrate estimates of the quantity of available resources and the costs of collection, processing and transportation to provide a picture of the delivered cost for biomass in each of the three counties for various supply quantities.

7.1 Agricultural Residue Cost and Supply

Developing the agricultural residue supply curves involved estimating the quantity and cost of available residue from barley, spring wheat, winter wheat, oats and grass crops delivered to the potential conversion sites in La Grande, Wallowa and Baker City shown in Figure 6-1. The purpose of the supply curve is to indicate the quantity and cost of agricultural residues for a biomass power or ethanol conversion facility in the study area. Quantities for agricultural residues are given in field-dry tons. Field dry residues may contain 10% to 20% moisture content.

7.1.1 Collection Costs

Residue collection costs were based on current custom harvest rates provided by two companies operating in Baker, Union and Wallowa Counties (Express Hay and North Slope Hay). Both operators break out their costs into swathing costs ($6/ton), baling costs ($14 to $15/ton), and stacking costs ($5 to $7/ton). Bales are the traditional three foot by four foot size. These costs were for fields having a minimum recovery of one ton per acre. The stacking cost assumed four to five miles as the maximum transport distance to where the stacks were stored.

7.1.2 Other Costs

Storage costs depend on the method chosen for storage. Methods include field/road side stacked, field/road side stacked and tarped, pad stacked, pad stacked and tarped and covered storage/pole barn. Storage costs vary with the method chosen. Selection of a storage method depends on the bale size, length of storage, location of storage, cost of storage and degradation. Storage costs for rice straw have been estimated by the Rice Straw Venture[60] to range from zero for uncovered field side stacks to $7 to $25/ton. We assumed storage costs would not be incurred for this study because uncovered field storage would be used. Residue has a fertilizer value depending on the amounts of nitrogen, phosphorus and potassium in the material. We assumed a fertilizer value of $3 per ton of residue removed that would be paid to the landowner. While this price represents the fertilizer value of the residue, it may not be sufficient compensation for growers.

These costs do not include any additional payment to the landowner. The current collection of wheat straw that goes to the animal bedding market operates on this basis. The farmer benefits by having reduced tillage expenses. Kentucky bluegrass residues are different because they have a feed value, and the farmer is paid $10 per ton.

[60] Rice Straw Feedstock Joint Venture, *Rice Straw Feedstock Supply Study for Colusa County California* (Western Regional Biomass Energy Program, 1999).

7.1.3 Transportation Costs

The cost of moving material from the farm to a conversion facility is mainly a function of the transportation distance. We chose the physical center of the wheat growing area within a county to compute the distance from the farm field to conversion facility. The road distances from the center to facility were measured using Microsoft MapPoint and tracing the roads to be used. Transportation costs were taken from the Rice Straw Feedstock Study.[61] The costs are computed as a fixed cost of $5.50/ton plus a cost of $0.088/mile. Thus, for a 50-mile haul, the cost would be about $10/ton. These costs are similar to those quoted by a local trucking firm.

7.1.4 Supply Curve Development

The supply curve is developed by determining the quantity of residue available and then estimating the cost of recovery and transportation to the facility. We developed supply curves showing the available quantity and cost of biomass delivered to the three potential sites identified in Section 6: Baum Industrial Park in Union County, Elkhorn View Industrial Park in Baker County and the former Bates mill site in Wallowa County.

The cost to transport biomass to potential conversion sites is estimated by first creating supply locations surrounding the conversion facility locations. Each supply location consists of a circle with a 4-mile radius. Since collection costs include delivery up to four miles, the center of the supply locations is chosen to encompass all agricultural land within a 4-mile radius of the center of the supply location. The lowest cost supply locations are the first areas that residue would come from. The first supply location is positioned at the conversion facility so there would be no transportation costs involved. As the demand increases, additional locations are added. The other supply locations are chosen and positioned so the total crop area is covered with a minimum number of supply locations. As the transportation distance increases, the marginal cost of residue will increase, but it is the average cost that is most important to the facility. The average cost is the cost of supplying all residue needed, divided by the total cost from each supply location.

Union County required a sublevel of computation to account for grass straw. Grass straw collection requires only raking, so the collection cost is only $24/ton compared to $26/ton for wheat straw. However, for Kentucky bluegrass, $10/ton is paid to the landowner to compensate for the feed value of the grass straw.

Table 7-1 gives the supply location, the quantity of residues within the four-mile radius of the supply location center, the transportation distance to the facility and the delivered residue cost for supplies within each county. For example, Union County required three supply locations to cover all agricultural land. The average cost is the total costs from all three locations divided by the total residues from all three locations. Thus, for Union County, the average cost is $32.25/ton to deliver 59,183 tons of residues. Supply costs for Baker and Wallowa were calculated in a similar manner.

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[61] Rice Straw Feedstock Joint Venture, *Rice Straw Feedstock Supply Study for Colusa County California* (Western Regional Biomass Energy Program, 1999).

Table 7-1. Agricultural residue availability and cost data for each county

Location			Residues	Transport	Costs ($)			
#	Latitude	Longitude	Tons	Miles	Total collection costs ($)	Total transport cost ($)	Marginal cost ($/ton)	Average ($/ton)
Union County								
1	N45 21.0	W118 2.0	11,245	0	305,684	0	27.18	27.18
2	N45 20.0	W117 53.7	22,490	8	611,367	139,526	33.39	31.32
3	N45 27.8	W117 57.5	25,449	9	691,810	160,124	33.48	32.25
Total/*average*			59,183	NA	1,608,861	299,650	NA	*32.25*
Baker County								
1	N44 47.7	W117 51.0	1,351	0	35,114	0	26.00	26.00
2	N44 52.1	W117 17.8	2,089	8	54,320	12,961	32.20	29.77
3	N44 53.1	W117 56.1	3,388	10	88,075	21,612	32.38	31.06
4	N44 59.3	W117 57.5	2,858	18	74,301	20,244	33.08	31.66
Total/*average*			9,685	NA	251,810	54,818	NA	*31.06*
Wallowa County								
1	N45 34.5	W117 31.9	811	0	21,095	0	26.00	26.00
2	N45 36.5	W117 23.9	1,210	8	31,468	7,509	32.20	29.71
3	N45 30.4	W117 23.4	1,487	12	38,659	9,748	32.56	30.92
4	N45 22.3	W117 8.4	1,538	26	39,983	11,976	33.79	31.79
5	N45 28.8	W117 4.2	1,281	31	33,313	10,542	34.23	32.29
6	N45 29.3	W117 12.1	1,458	25	37,914	11,228	33.70	32.55
7	N45 40.0	W117 1.8	1,240	44	32,228	11,617	35.37	32.94
9	N45 30.7	W117 17.8	723	18	18,809	5,125	33.08	33.21
8	N45 34.9	W117 3.9	1,391	40	36,171	12,548	35.02	33.22
Total/*average*			11,139		289,640	80,293		*33.22*

Note: NA means not applicable.

Supply curves were also developed for each county site assuming that one county received all the agricultural residues available in the three county area (Table 7-2).

Table 7-2. Agricultural residue availability and cost data for all counties combined

Centroid	Tons	Haul distance in miles from centroid to site in:			Delivered cost ($/ton) from centroid to site in:		
		Baker County	Union County	Wallowa County	Baker County	Union County	Wallowa County
U1	11,245	44	0	41	36.56	27.18	36.29
U2	22,490	52	8	33	37.26	33.39	35.59
U2	25,449	53	9	32	37.35	33.48	35.50
B1	1,351	0	44	85	25.99	35.36	38.97
B2	2,089	8	36	77	32.21	34.67	38.28
B3	3,388	10	34	75	32.38	34.49	38.10
B4	2,858	18	26	67	33.08	33.79	37.39
W1	811	85	41	0	38.99	35.12	26.01
W2	1,210	93	49	8	39.69	35.82	32.21
W3	1,487	97	53	12	40.03	36.16	32.55
W4	1,538	111	67	26	41.26	37.39	33.78
W5	1,281	116	72	31	41.71	37.84	34.23
W6	1,458	110	66	25	41.18	37.31	33.70
W7	1,240	129	85	44	42.84	38.97	35.36
W8	1,391	125	81	40	42.50	38.63	35.02
W9	723	103	59	18	40.58	36.71	33.10
Total	80,009						

The information from Table 7-2 was used to develop charts showing the agricultural residue supply in each county.

Figure 7-1 shows the supply curves for Baker, Union and Wallowa Counties, assuming residues from all three counties can be delivered to the hypothetical conversion facility site in each county. For Union County, the rate of cost increase slows when the quantity demanded increases to approximately 35,000 tons. For Baker and Wallowa Counties, the rate of cost increase is much steeper for smaller quantities than for Union County.

In all three counties, a commercially viable cellulose-to-ethanol plant would need all of the available agricultural residues and a significant quantity from outside the study area. Therefore, the facilities would not be likely to be able to take advantage of lower prices available at smaller supply quantities. At the high end of the supply curve, Union County has the least costly agricultural residues at $33/GT delivered, followed by Wallowa County at $36/GT and Baker County at $37/GT. However, site-specific variability in agricultural residue collection, processing and transportation costs could make this cost distinction between the counties unimportant.

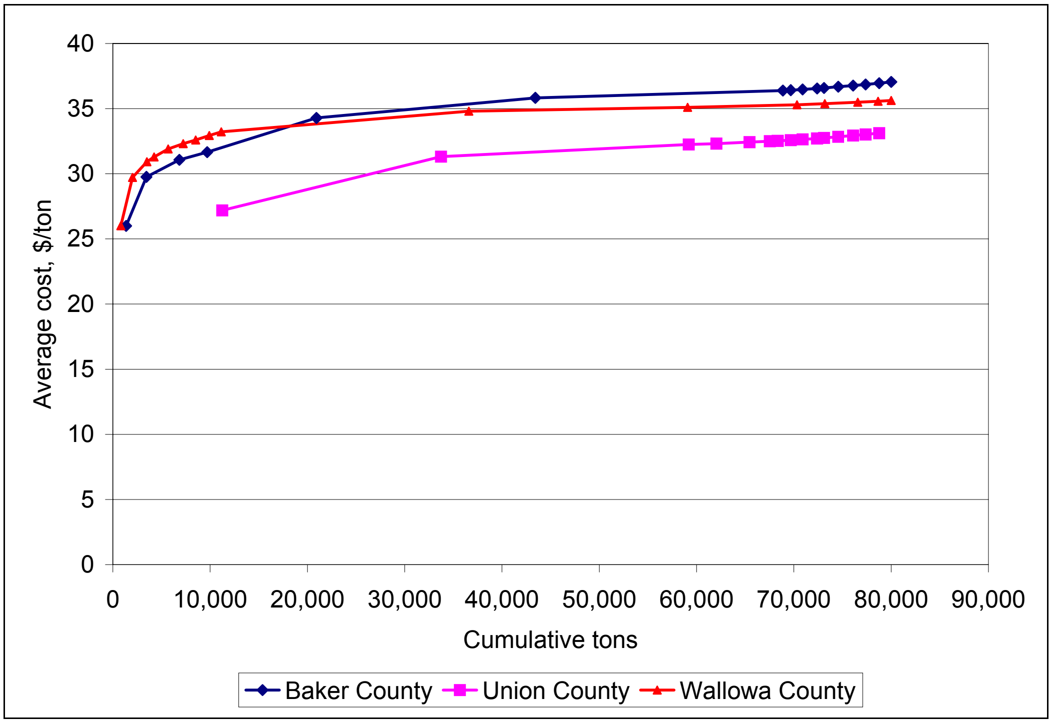

Figure 7-1. Agricultural residue supply curve for Baker, Union and Wallowa Counties, using residues from all three counties in study area

7.1.5 Logistics of Recovery

The infrastructure for collection, storage and transportation of large quantities of wheat straw does not currently exist in Oregon. The Isobord facility in Canada is an example of meeting infrastructure needs. Isobord is not necessarily a model for Oregon, but it is an example of what others have done. Isobord produces strawboard from wheat straw. They purchase straw from a farmer co-op with 450 members for $5/ton. In 1998, they harvested and transported 176,000 tons of straw to the plant. The straw was transported directly to the plant and not stored on the farm. Isobord purchased 36 tractors and balers and provided the labor for collection and transport.

The number of landowners a conversion facility must contract with is a question that should be addressed. The Canadians formed a co-op so Isobord only had to deal with one entity rather than 450 individual landowners. An estimate of the number of landowners can be made for the study area based on the average farm size per county. There are 277 wheat farms and 57,190 planted acres in the study area. The majority of the land is on farms greater than 500 acres. Fifty farms account for over 50% of the wheat acreage in the three counties. Figure 7-2 shows the size distribution for wheat farms in the three Oregon counties. There appears to be a reasonable number of farms that could supply straw to a conversion facility without requiring a large number of contracts. Nevertheless, a farm supply co-op may prove to be the best contracting arrangement, but that remains to be evaluated.

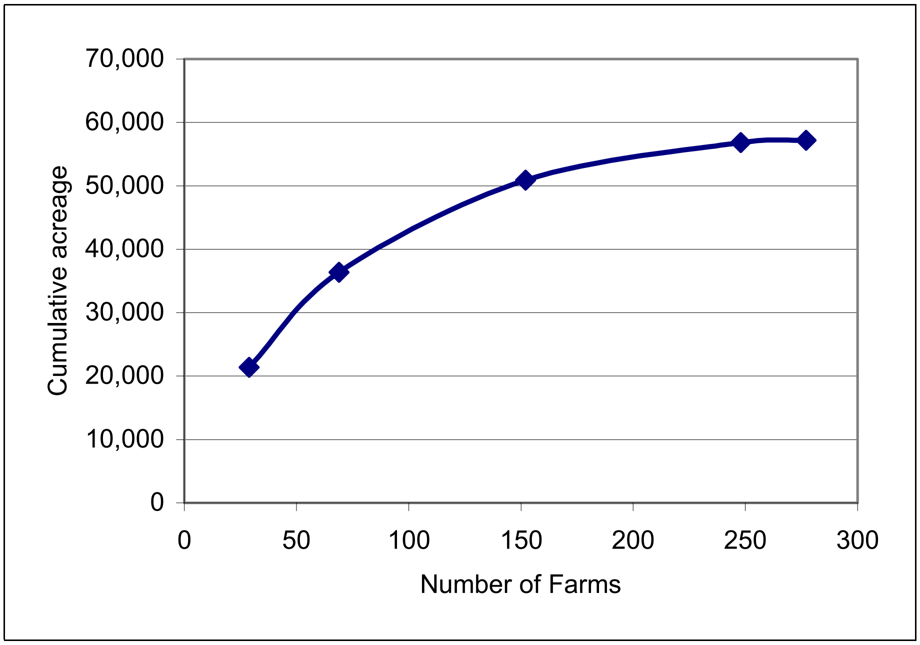

Figure 7-2. Wheat farm size distribution

7.2 Forest Biomass

The supply curves for forest biomass were developed using a similar approach to that for agricultural residue: by developing the quantity of residue available and the costs for collecting, processing and transporting that residue from the forest to potential conversion sites.

7.2.1 Collection and Processing Costs

Methods used to collect and process forest biomass vary from site to site, based on slope, climate, soils, forest stand density and a variety of other site-specific factors. This section discusses methods and costs for collecting and processing forest biomass from thinning projects and timber harvesting residues.

In forest thinning projects, whole, small diameter trees and understory brush are removed to reduce forest density and obtain the desired forest structure. Removing trees is accomplished in three primary steps: felling (cutting the trees to be removed), bucking (cutting trees to length) and delimbing, and forwarding downed trees to a landing site for further processing and transportation to a conversion facility.

Felling is typically accomplished manually with chainsaws or mechanically using a feller-buncher, which can grasp and cut trees. When cut trees are bucked in the woods, the resulting logs can be loaded onto a forwarder for transportation to the roadside. A forwarder typically consists of a rubber-tired modified tractor with a grapple loader and a log trailer. Alternatively, logs can be transported to a landing site in the woods for processing using a skidder, which is a rubber-tired machine with grapple or cabled drum that drags partially-suspended whole trees. A crawler is similar in function to a skidder but it has tracks, rather than tires.

Table 7-3 summarizes the types of felling, processing and primary transportation systems used in forest management operations that can also be used to supply biomass for energy applications.

Table 7-3. Overview of common types of forest biomass harvest systems

Common harvesting systems	Felling	Processing	Primary transportation
Conventional Ground Based	Manual	Manual bucking	Skidder or crawler
Mechanized Ground Based	Feller-Buncher	At landing	Skidder or crawler
Mechanized Ground Based	Feller-Buncher	In woods	Forwarder
Mechanized Ground Based	Cut-to-Length	Cut-to-Length	Forwarder

Source: T. Keatley, *Harvesting Options in Small Diameter Stands Operating on Gentle Slopes* (University of Idaho, October 2000).

In conventional timber harvest operations, tops and branches are often lopped and scattered, left in skid trails to reduce soil disturbance or piled on-site to be burned later. However, a portion of these residues can be collected and transported to a landing for chipping or grinding.

Systems for collecting and transporting timber harvest residue are similar to those for harvesting whole, small diameter trees. It is typically less costly to utilize timber harvesting residue with a mechanized, ground-based system that processes trees at a landing site. In such a system, the whole tree is transported to a landing site, where it is delimbed and cut to length. Then a grapple loader can be used to load timber residue directly into a chipper or grinder and skidder/crawler equipment, and labor is not used to transport low value materials. A cut-to-length felling and processing system fells, bucks and delimbs trees in the forest in one process. Cut trees can then be forwarded to a roadside area for transportation to a mill. Cut-to-length systems are best for operations in medium-size (7 to 18 inches DBH) forest stands.[62] Cut-to-length systems can cost more than other mechanical ground-based systems.

Processing typically occurs at forest landing sites in order to increase the density of the biomass for transportation, thereby reducing trucking costs. In this way, more biomass weight can be shipped per truckload. The most common methods of processing residue into denser biomass material at a landing site include chipping and grinding. Chipping often produces a uniform size and shape product for feedstock handling systems for either biomass power generation or ethanol manufacturing.

Table 7-4 provides estimates of roadside forest biomass costs based on time and motion studies for the western United States. Roadside is an encompassing term that captures costs associated with felling, skidding, chipping and loading material into a chip van for transport.

[62] T. Keatley, *Harvesting Options in Small Diameter Stands Operating on Gentle Slopes* (University of Idaho, October 2000), p. 5.

Table 7-4. Range of roadside-chipped forest biomass costs and yields

Project	Roadside chip cost ($/GT)[a]
Ponderosa Pine Partnership[63]	
Unit 1	41.76
Unit 4	46.41
Unit 5b	39.06
Unit 5e	29.80
Wyoming time and motion studies[64]	
Wyoming – Neuson	41.68
Wyoming – Manual	30.88
Average	38.26

[a] Chipping costs for both the Ponderosa Pine Partnership and Wyoming time and motion studies were assumed to be $ 6.39/GT. Source: S. Haase and T. Rooney, NEOS Corporation, *Evaluation of Biomass Utilization Options in the Lake Tahoe Basin* (U.S. DOE Western Regional Biomass Energy Program, September 1997). Chipping cost estimates were escalated from 1997 values to 2003 using an assumed 2% inflation rate.

Bundling systems that produce bales for transportation to a conversion site are beginning to see use in the U.S. as an alternative to chipping and grinding in the forest. These systems could reduce the costs of biomass, but to be conservative, we assumed that biomass would be chipped and blown into a chip van for transport. A John Deere bundling system (Figure 7-3) was demonstrated west of La Grande in July 2003, in a project sponsored by the Oregon Department of Forestry, USFS, Union County Extension Service, John Deere and Jim Voelz (landowner).

[63] D. Lynch and K. Mackes, *Evaluating Costs Associated with Fuel Hazard Reduction and Forest Restoration Projects in Colorado* (Department of Forest Sciences, Colorado State University, 2002).
[64] J. Klepac and R. Rummer, *Smallwood Logging Production and Costs: Mechanized vs. Manual* (ASAE International Meeting, July 28-31, 2002, Paper Number 025007).

Figure 7-3. John Deere 1490D slash bundler system demonstrated in La Grande, Ore.

7.2.2 Transportation Costs

Most frequently, forest biomass is transported by a tractor trailer-drawn chip van to a conversion facility or to a rail-loading site for transportation by rail. For this study, we assumed that transportation would be by truck.

Truck transportation costs will vary, but the value used for agricultural residue transportation, $5.50/ton fixed cost and $0.088/mile transported, is also a reasonable value for forest biomass transportation. This value was used for the supply curve analysis and for economic analysis of biomass power plant scenarios in Section 0. Costs may be lower if arrangements such as back hauls can be made to use empty chip vans on a return trip from another location. However, because it is likely that the location of forest management projects will change, relying on lower costs for planning purposes is not prudent.

7.2.3 Supply Curve Development

An analogous methodology to that used for agricultural residue was used to develop the supply curves for forest biomass. Forest biomass collection and processing costs were added to transportation costs to determine an average delivered forest biomass cost at each of the potential conversion sites. Transportation costs were calculated based on haul distance from the supply location to the conversion facility. A similar method to that used for agricultural residues was used to estimate the transport distance from the center of supply locations within the study area

(Figure 7-4) to potential biomass conversion sites. The supply radii in Figure 7-4 exclude federal wilderness study areas and national recreation areas. Each supply radius is assumed to represent an equal proportion of the total quantity of available forest biomass.

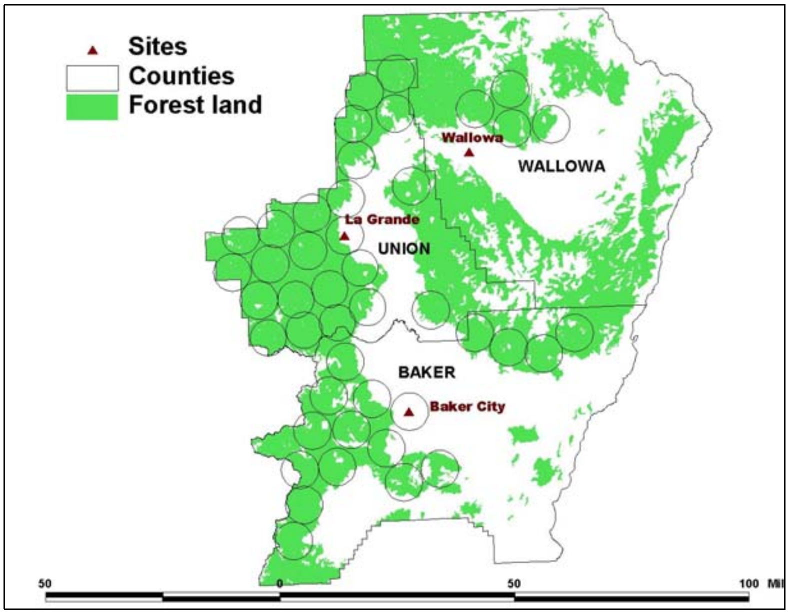

Figure 7-4. Forest biomass supply locations

Rather than trace the road-hauling route for the many supply locations in the area, transport distances were estimated by multiplying the number of supply locations by eight miles, the distance between the centers of supply locations. We multiplied this value by 1.5 to account for road curvature and to provide a conservative estimate of haul distance.

Unlike agricultural crops that are frequently planted in the same area, there is uncertainty about which forest areas will be subject to management activities from year to year. Therefore, the quantity of forest biomass coming from each supply location was estimated by multiplying the percentage of total forest area in each supply location by the total forest biomass availability.

Estimated biomass costs and available quantities were used to develop supply curves for potential processing sites in each of the three counties (Figure 7-5). The curves provide a basis for showing the difference in fuel supply economics for power plants of different sizes. The supply curves appear similar in shape because there is relatively little information about the geographic distribution of potential forest management sites in the study area. The primary difference in supply cost between the counties is due to differences in transportation costs.

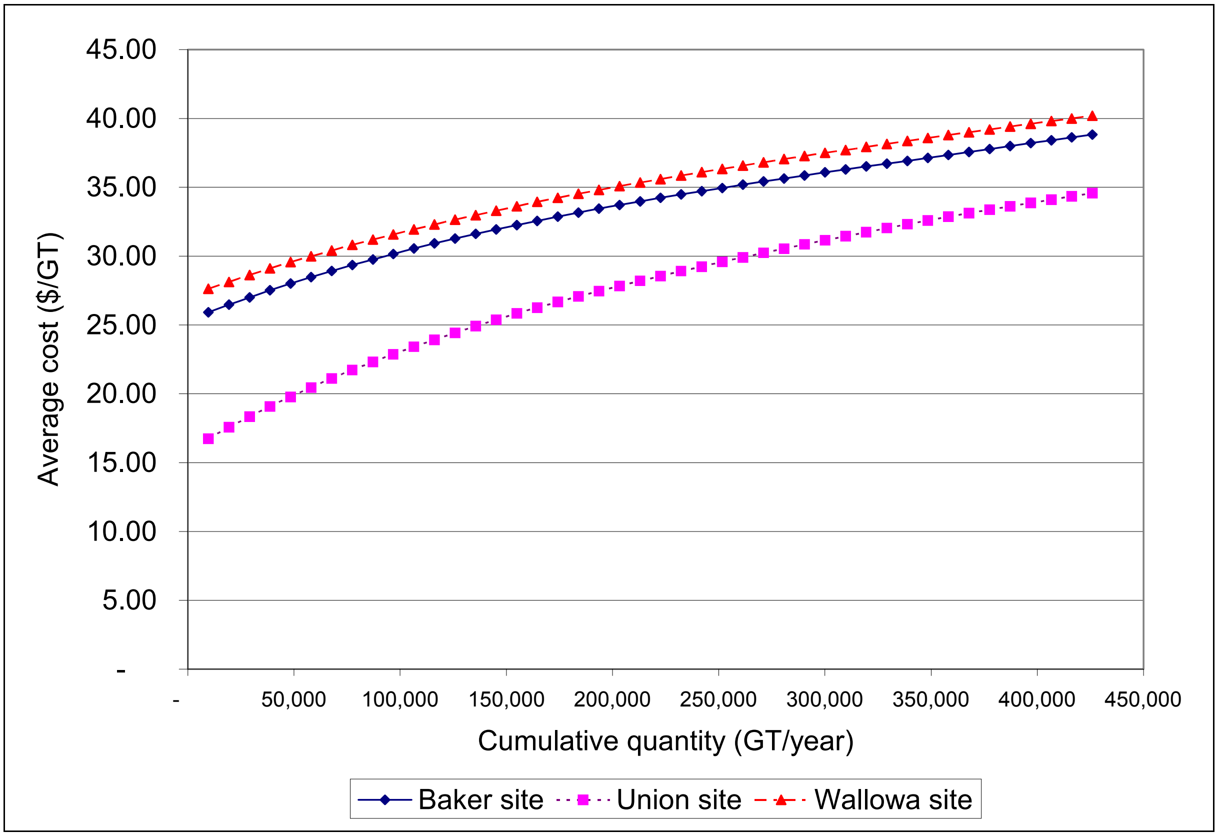

Figure 7-5. Forest biomass supply curves for potential conversion sites in Baker, Union and Wallowa Counties

Better data on the location of overstocked stands would permit a more accurate analysis of the geographic distribution of the biomass resource. This would require public and private landowners to plan forest management efforts for several years into the future. Geographic information systems (GIS) software could then be used to map out the locations of projects, estimated biomass availability and costs specific to each project.

7.2.4 Logistics of Recovery

Developing the forest biomass supply in the region will require participation by federal agencies, state agencies, private landowners and existing forest management practitioners in the area. Due to the current and historic background of the region with conventional forest products, the transition to utilizing forest biomass will be easier than in many other areas in the Western U.S.

Forestland managers in the region are committed to conducting active management to meet fuels reduction and watershed quality objectives, which will be vital for the development of a biomass energy infrastructure. The USFS is the single largest forest landowner in the region; the largest single private landowner is Boise Cascade. Both of these major landowners actively conduct fuels reduction and other non-commercial thinning on their forestland. Coordination between the two major landowners in mid- to long-range management planning would help ensure a stable supply. Current federal land management information on planned project acreage and treatment type is insufficient to do detailed, operational planning for a biomass conversion facility. Biomass supplies from private land may be sufficient to support a bioenergy plant, but multiple-year project planning on federal land would reduce the risks of short-term supply shortages that would drive up costs if land management patterns change on a single landownership. In addition, consistent management patterns and cooperation across landowners will increase the overall effectiveness of forest and watershed management strategies. It would also be necessary to support increased investment in forest management equipment and employees in the area.

The current supply infrastructure is capable of collecting and processing small diameter forest biomass for energy applications. There are existing chipping operations that operate in and near the study area that supply pulp to regional paper operations. These operators have the expertise to expand and adapt their chipping operations to include the utilization of small-diameter materials for energy, should a market for such materials develop. Trucking companies in the region that have in-woods chipping operations will be able to transport chips for energy applications as well, but some ramp-up of capacity may be required.

7.3 Wood Products Residues

Residue from the existing wood products industry (mill residue) is currently fully utilized. It is likely that only a portion of the residue generated would be available because much of the supply is utilized internally to support existing particleboard manufacturing capacity. Therefore, the wood products residue supply in the region is limited to chips currently sold for pulp and a small quantity of veneer cores that are sold sporadically for post and pole operations.

The total quantity of chips and veneer cores generated annually in the region is 310,252 GT. The entire quantity may not be available immediately because of multiple supply contracts, and the price would have to be competitive with the existing use. Table 7-5 shows the cost of wood products residues delivered to the potential conversion sites. La Grande, Ore. generates the bulk of the residues. Therefore, the primary cost difference between the regions is the difference in transportation. A price premium may be needed to entice residue generators to switch outlet markets, so the costs in Table 7-5, based on current prices, could be an underestimate. There is, however, little means of determining the price-sensitivity of suppliers until an offer is made to purchase the residues.

Table 7-5. Wood products residue supply costs delivered to conversion sites

Type	Price at mill ($/GT)	Transport distance (miles)			Transport costs ($/GT)			Total costs ($/GT)		
		Union site	Baker site	Wallowa site	Union site	Baker site	Wallowa site	Union site	Baker site	Wallowa site
Chips	$15.93	0	45	65	0	9.46	11.22	$15.93	$25.39	$27.15
Veneer cores	$3.00	0	45	65	0	9.46	11.22	$3.00	$12.46	$14.22

The residue supply price is subject to fluctuations associated with markets for lumber, paper pulp, plywood and particleboard that could affect the cost-effectiveness of this supply. The cyclical nature of pulp chip prices, in particular, could affect availability of this supply. In the past, prices for clean chips from sawmills have been as high as $60/GT, which would make this residue supply source as costly as forest biomass. This is why reliance on low pulp chip prices as a basis for economic analysis of a potential biomass power or ethanol manufacturing facility is a risky assumption.

7.4 Regional Biomass Supply Curve – All Sources

Biomass supply curves show how the average price that a biomass energy facility would pay per delivered ton changes as the total quantity of feedstock needed increases. The biomass supply consists of forest biomass, wood product manufacturing residue and agricultural residue. Biomass supply curves were developed based on estimated biomass availability and feedstock costs delivered from the entire three-county study area to one potential plant location within each county.

The first step in developing the supply curves was to estimate biomass availability for forest biomass, manufacturing residue and agricultural residue. Forest biomass included residue from timber harvesting, fuels reduction, timber stand improvement and non-commercial thinning on both public and private land. The estimated quantity of biomass from timber harvesting was based on a 10-year average of timber harvest volume. It was assumed that fuels reduction, timber stand improvement and noncommercial thinning projects would yield 10 GT of biomass per acre of forestland treated. This yield assumption was chosen to represent a conservative yield value; in practice, biomass yields can range from as little as two GT per acre to as much as 30 GT per acre. Forest biomass was considered available from forest management projects on land with slopes less than or equal to 30%. Section 3 provides more details about how forest biomass generation and availability were estimated. Wood product manufacturing residue generation and availability were determined by a survey of local manufacturers. Section 4 discusses manufacturing residue availability in more detail. The quantity of agricultural residues available was estimated based on historical crop production data, residue generation factors based on crop yield and soil conservation requirements. Section 5 provides more details on how agricultural residue generation and availability were estimated.

The next step to develop the biomass supply curves was to estimate delivered biomass costs to the potential plant sites in each county. Costs to collect and transport forest and agricultural biomass to a roadside location for transportation to a biomass energy facility were based on published values. Transportation distances were estimated for forest and agricultural biomass from four mile radius supply areas, each representing a portion of the agricultural or forest biomass supply, to potential plant sites within each county. Transportation costs were estimated assuming $5.50 fixed cost per GT of biomass plus $0.088 per GT-mile. Delivered costs were the sum of roadside and transportation costs. Supply curves specific to potential plant locations were then developed by sorting biomass supply sources in order of ascending cost. Then weighted average biomass costs were calculated to show the average cost a biomass facility operator would expect to pay per GT delivered as the quantity demanded changes.

There are really two biomass supply curves for each potential plant site - one for biomass power and one for ethanol. The difference is that there can be technical issues associated with burning agricultural residue in many boiler systems. Therefore, agricultural residue is not included in the supply for biomass power systems. Should it be necessary and if it is technically feasible, agricultural residue may be utilized in a biomass power system, but this will not greatly affect the cost of the overall supply. For ethanol, there is not enough agricultural residue available in the study area to support a cost-effective ethanol plant, based on current near-commercial cellulose ethanol technologies. This makes it necessary to evaluate forest biomass and mill residue as part of the supply. Using all biomass sources at a single plant may require separate feedstock handling and processing systems and possibly more care in blending the feedstocks or switching between them as they are available. However, this is not likely to be an insurmountable technical issue.

The biomass power supply curve in Figure 7-6 includes only forest biomass and mill residues. For the biomass power supply curve, the lowest cost supply is from mill residue chips, with the exception of a small quantity (1,458 GT) of veneer cores, which can be purchased for $3/GT, but require further processing. The primary difference in cost between the sites is associated with transportation. Union County has the lowest-cost biomass supply, primarily because the difference in transportation costs for mill residues. However, chip markets can be volatile. An increase in chip prices of $10/GT could eliminate the cost advantage that the Union County site currently has over other sites. A price swing of this magnitude is consistent with past price volatility for pulp chips. In contrast, forest biomass is at the high end of the cost curve.

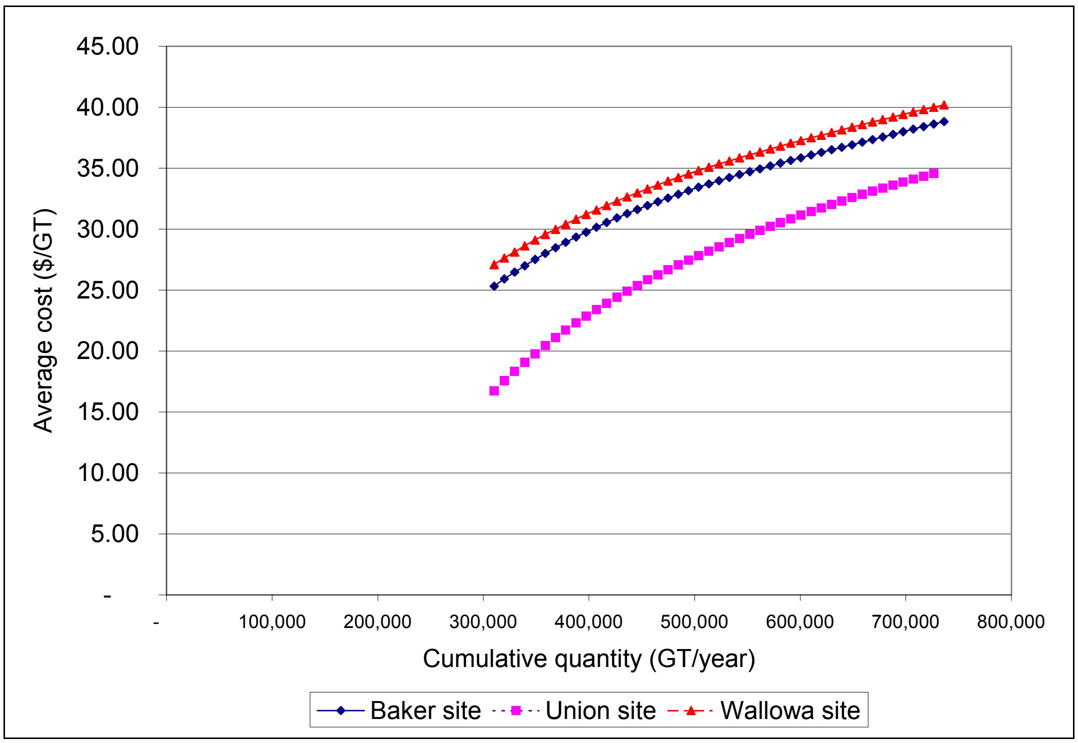

Figure 7-6. Biomass supply curve for biomass power plant

The ethanol supply curve shown in Figure 7-7 includes all residue sources. The least expensive supply source is mill residue. Agricultural residue is the next least costly at quantities less than approximately 300,000 GT. For a biomass ethanol facility, the higher-cost forest biomass would be utilized as the feedstock requirement for the facility exceeds about 400,000 GT/year, athough even at lower feedstock requirements, some forest biomass may be used to fill in periods of short supply of other resources. Forest biomass might also be used when mill residue chips cannot be purchased at a competitive price.

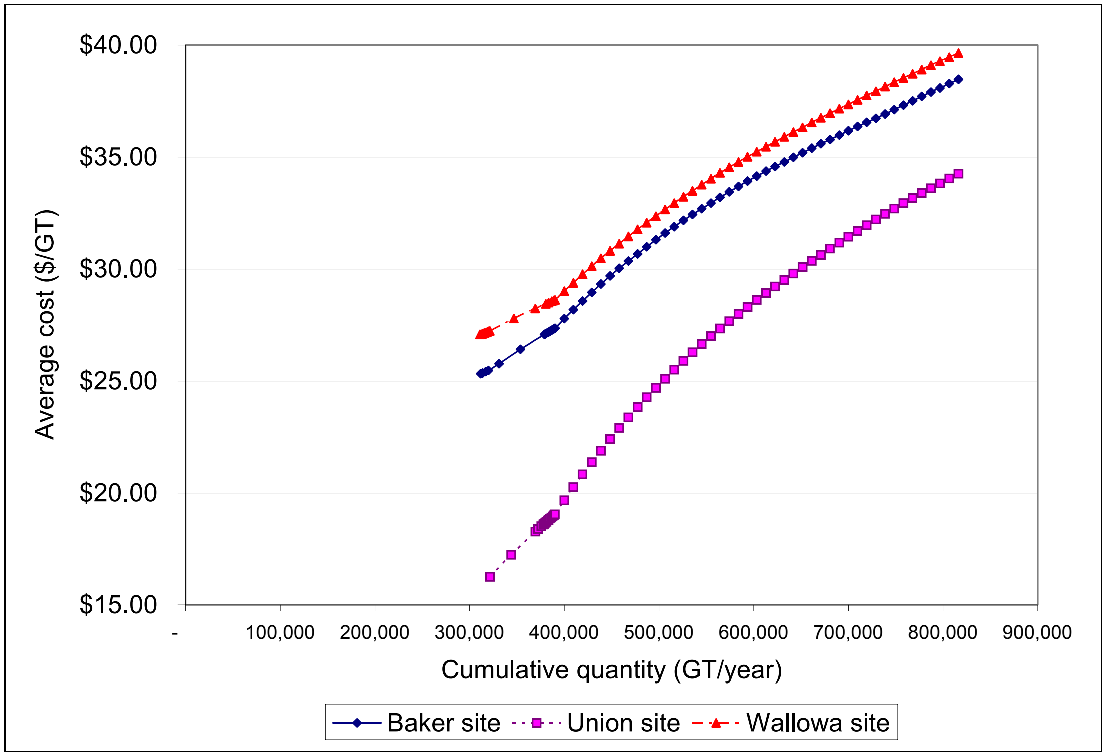

Figure 7-7. Biomass supply curve for cellulose ethanol facility

Table 7-6 shows the supply quantity and weighted average cost for the biomass supply for a biomass power or cellulose ethanol plant in each of the three counties. The weighted average cost in Table 7-6 is the uppermost bound on the average cost. It shows the annual average cost a biomass energy facility would expect to pay if it used all of the available residues in the study area. The overall quantity available is the same for each county for biomass power or ethanol. The overall quantity is larger for an ethanol plant due to the inclusion of agricultural residue in the supply. The average cost for an ethanol plant would be slightly lower than the average cost for a biomass power plant, because the use of agricultural residue reduces the average feedstock cost for an ethanol plant.

Table 7-6. Supply availability and cost in Baker, Union and Wallowa Counties

Supply source	Quantity (GT/year)	Baker County – Biomass cost ($/GT)			Union County – Biomass cost ($/GT)			Wallowa County – Biomass cost ($/GT)		
		Min	Max	Weighted average	Min	Max	Weighted average	Min	Max	Weighted average
Cellulose ethanol										
Agricultural residues[a]	80,009	25.99	37.04	35.24	27.18	33.21	31.39	26.01	35.63	34.31
Forest biomass[b]	425,934	44.82	54.32	48.66	44.82	52.21	48.20	44.82	54.32	49.49
Mill chips[c]	308,794	25.39	25.39	25.39	15.93	15.93	15.93	27.15	27.15	27.15
Veneer cores[c]	1,458	12.46	12.46	12.46	3.00	3.00	3.00	14.22	14.22	14.22
Total	816,195			38.47			34.26			39.51
Biomass power										
Forest biomass[b]	425,934	44.82	54.32	48.66	44.82	52.21	48.20	44.82	54.32	49.49
Mill chips[c]	308,794	25.39	25.39	25.39	15.93	15.93	15.93	27.15	27.15	27.15
Veneer cores[c]	1,458	12.46	12.46	12.46	3.00	3.00	3.00	14.22	14.22	14.22
Total	736,186			38.82			34.57			40.19

[a] Available agricultural biomass includes straw from winter wheat, Kentucky bluegrass seed production and other grass seed production. Availability was calculated based on the quantity of residue needed to be left on-site to maintain soil productivity. Section 5 provides more information on agricultural residue generation and availability.

[b] Forest biomass consists of timber harvesting residue and forest biomass from fuels reduction, timber stand improvement and noncommercial thinning activities. Timber harvesting residue generation was estimated based on historical timber harvest volumes. Biomass from fuels, timber stand improvement and noncommercial thinning projects assumed a yield of 10 GT per acre treated. Forest biomass was considered available only from forestland with slopes less than 30%. See Section 3 for more information on forest biomass generation and availability.

[c] Mill residue chips are currently sold for pulp, but are not under long-term contracts. Mill chip prices are subject to variability that is not reflected in this study. Figures shown here represent annual average mill prices for 2002. There is little or no current market for veneer cores, which need to be chipped prior to utilization for biomass energy. Section 4 provides more information on mill residue generation and availability.

8. BIOMASS CHARACTERIZATION

This section describes the physical and chemical characteristics of various forms of biomass that are likely to affect power and ethanol manufacturing feasibility in the study region.

8.1 Biomass Fuel Characteristics

Biomass can be converted to thermal energy, liquid, solid or gaseous fuels and other chemical products through a variety of conversion processes. These processes include physical conversion to "densified" fuels (e.g. pellets or cubes), thermal conversion through combustion or pyrolysis, chemical conversion, and microbial conversion or fermentation. The abundance of plant organic constituents and other physical and chemical characteristics vary significantly by plant type and the proportions of plant components such as leaves, stems, bark and twigs in the feedstock. Design of a biomass power or ethanol facility requires careful consideration of the effects that feedstock characteristics and composition have on the conversion process. Table 8-1 describes the key factors that affect the product yield in biomass conversion processes.

Table 8-1. Feedstock characteristics that affect biomass conversion processes

Characteristic	Conversion process				
	Physical	Combustion	Pyrolysis	Gasification	Fermentation
Physical characteristics					
• Density	✓	✓			
• Particle size & distribution	✓	✓	✓	✓	
Moisture content	✓	✓	✓	✓	✓
Energy content		✓	✓	✓	
Non-combustibles					
• Ash content		✓	✓		✓
• Ash composition		✓	✓	✓	✓
• Sulfur content		✓	✓	✓	
Bulk / biochemical composition					
• Plant type	✓	✓	✓	✓	✓
• Plant components	✓	✓	✓	✓	✓
• Carbohydrate / non-carbohydrate proportions			✓	✓	✓
• Cellulose / hemicellulose proportions					✓
• Volatiles		✓	✓	✓	✓

Generating electricity and useful heat energy is most frequently done by direct combustion of biomass in a boiler. Energy content, moisture content and chemical makeup are among the most important biomass characteristics affecting combustion processes. Biomass gasification yields a combustible gas that can be used to generate electricity. Particle size, energy content, moisture content and volatiles are among the biomass characteristics affecting gasification.

The technology that is closest to commercialization for converting biomass to ethanol involves extracting complex carbohydrates, primarily cellulose and hemicellulose, from the biomass feedstock and reducing these components to simple sugars (a process called hydrolysis). Cellulose is a long polymer of glucose, and it serves as a structural component of plant cell walls. It is often found in a composite mixture with hemicellulose and lignin. Hemicellulose is a polymer containing a variety of simple sugars and is more soluble than cellulose. Lignin is a ring-type carbohydrate that acts as cement in plant walls.[65] The lignin portion of biomass is not converted to simple sugars through hydrolysis, but lignin can be burned to generate process heat and electricity.

Extracting the carbohydrates may involve "steam explosion" of the cell walls or dissolving the organic constituents with acids, enzymes or organic solvents. Sugars resulting from hydrolysis are then converted into ethanol through microbial fermentation. The bulk and biochemical composition of the feedstock largely determine ethanol yield because these traits affect the hydrolysis and fermentation processes.

8.1.1 Physical Characteristics

The physical characteristics of the various feedstocks will affect any technology option considered for development in the region. Physical characteristics, including particle size, density and moisture content, add important considerations for transportation and material handling as well as for conversion process efficiencies. Nearly all biomass energy conversion processes require some form of physical manipulation of the fuel. This may include sorting, storing, sizing, screening and moving the material from one location to another. Because low-density materials occupy more space in truck trailers, they cost more per unit of weight to deliver and thus increase feedstock costs. For most biomass energy applications, forest biomass will be transported in chip form in order to increase the quantity of material that can be transported per truckload. Forest biomass often, but not always, includes significant quantities of tops, branches and foliage that preclude the use of conventional log trucks for transportation. However, as discussed in Section 7.2.1, slash bundling equipment that permits transport of compressed bundles can increase truck capacity over chip vans. Agricultural residue moisture content is often low but volume is a limiting factor on the quantity of material that can be transported, which is why baling is a necessity.

In general, the smaller the feedstock particle, the more rapid and complete the conversion process, whether it is a drying process, biomass combustion or the enzymatic hydrolysis of cellulose. The process design often determines the optimum range of particle sizes and particle size distribution. Density and particle size are frequently controlled in the pre-treatment process through chipping, shredding, grinding and screening, depending on the process and biomass type.

8.1.2 Moisture Content

Moisture content (MC) is the most important characteristic affecting the quality of biomass fuel for thermal processes like combustion, gasification and pyrolysis. Materials with lower moisture content cost less to transport and can reduce the size of handling, processing and energy conversion equipment needed for biomass power because a smaller volume of feedstock would be required to meet the fuel requirements for a plant. On the other hand, high moisture content is desirable for a microbial fermentation process, where a liquid water medium is essential. This

[65] H. Bungay, *Introduction to Sugar Structures: Starch/Cellulose* (http://www.rpi.edu/dept/chem-eng/Biotech-Environ/FUNDAMNT/cellulos.htm, Rensselaear Polytechnical Institute, Department of Chemical Engineering, March 6, 1998).

section discusses moisture content and its effects on both biomass power and cellulose ethanol processes.

Moisture content can be measured on a wet or a dry basis. The wet basis method, in which the moisture content is expressed as a percentage of the total weight, is usually used in engineering calculations. In forest product calculations, the dry basis method is used, in which the moisture content is expressed as a percentage of the dry weight of the wood. For example, a two-pound piece of wood may consist of one pound of wood biomass and one pound of water. Using the wet basis method, the moisture content would be expressed as 50%. Using the dry basis method, the moisture content would be 100%. This report uses the wet basis method.

The moisture content of freshly harvested forest and crop residue typically varies from 40% to 60% by weight, and can be higher, especially if the residue exposed to precipitation.[66] The moisture content of crop residue, such as cereal straws, can be reduced to 15% or less by open-air solar drying. By contrast, wood residue typically ranges from 18% to 25% MC or more after air-drying for approximately one year, depending on climate, storage conditions and bulk characteristics. Bark often has lower moisture content than wood. Moisture content can be influenced by weather. Under drought conditions, the moisture content of standing live trees can drop below 20%, adding to the threat of wildfires.

In combustion processes, high moisture content can lead to incomplete combustion, low thermal efficiency, low flame temperatures, excessive emissions and the formation of tars that could cause slagging problems. Maximum thermal efficiency is achieved at zero moisture content, referred to as oven-dry (OD) or bone-dry (BD); but complete drying is often too costly or impractical. Woody and herbaceous biomass with moisture content in the range of 10% to 20% is considered optimal for conventional combustion systems.[67] Low moisture content is especially important for most pyrolytic gasification processes, where variations in the moisture content of the feedstock cause large variations in the quality of the gas product.[68] Drying costs must be weighed against the advantages of handling drier feedstock and incremental improvements in the conversion process. Some fluid-bed combustors, however, are designed to operate with variable moisture content of the feedstock up to 50%. Many large-scale combustion plants operate well with little apparent concern for the effects of moisture content in the biomass feedstock on the combustion process.[69] Pre-treatment involving size reduction and air drying, and/or blending with dry fuel may be adequate and cost-effective for such operations.

Biomass feedstocks with high moisture content have higher transportation costs because a large proportion of the weight being shipped is water. Because of the negative impact of moisture content on combustion processes and increases in delivered feedstock costs, a good rule is to attempt to minimize moisture content of the feedstock. This can be done by using a blend of feedstocks, including lower moisture content mill residue such as sawdust to offset higher moisture content forest biomass. Alternatively, it is possible to reduce moisture content through passive or active drying. For ethanol feedstock, the increased delivered costs of biomass with higher moisture content probably outweigh the costs of increased process water requirements, but this needs to be examined on a site-specific basis.

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[66] Klass, *Biomass for Renewable Energy, Fuels, and Chemicals* (Academic Press, 1998), p. 161.
[67] Ibid, p. 197.
[68] Ibid, p. 165-67.
[69] Ibid, p. 163.

8.1.3 Energy Content

Thermal energy is released from organic materials as the carbohydrates and other hydrocarbons (lignin and volatile chemicals) are ultimately reduced to carbon dioxide and water. The amount of usable thermal energy that can be obtained from fuel is known as the higher heating value (HHV). By contrast, the lower heating value (LHV) is equivalent to the HHV of the fuel minus heat required to vaporize the liquid water of the fuel. Interestingly, on a dry, ash-free basis, most biomass has about the same energy content (HHV) of 8,000 to 8,500 British thermal units per pound (Btu/lb).[70] However, the practical heating value of biomass, as received, varies considerably due to differences in the content of ash-forming minerals and moisture.

Table 8-2 shows the HHV, ash content and moisture content of various plants that are common in Northeastern Oregon. The importance of the ash content will be discussed below.

Table 8-2. Heat, moisture and ash content of tree and crop residue

Plant variety	HHV (Btu/lb)	Field MC (wt %)	Ash (wt %)
Softwoods			
Ponderosa pine	8,613	40-60	0.29
White fir	8,582	40-60	0.25
Western hemlock	8,626	40-60	0.2
Douglas-fir	8,733	40-60	0.8
Douglas-fir bark	9,507	40-60	1.2
W. white pine	8,905	40-60	0.1
Loblolly pine	8,733	40-60	0.5
Loblolly pine bark	9,370	40-60	0.4
Slash pine bark	9,365	40-60	0.7
Pine wood	9,137	40-60	0.5
Pine shavings	8,337	40-60	1.43
Pine bark	8,776	40-60	2.9

Plant variety	HHV (Btu/lb)	Field MC (wt %)	Ash (wt %)
Hardwoods			
Red Alder	8,303	40-60	0.4
Black Alder	8,647	40-60	1
Aspen	8,776	40-60	4.1
White Oak	8,354	40-60	1.52
Poplar	8,927	40-60	0.57
Crop residues			
Barley straw	7,929	10-20	8.96
Wheat straw	7,627	10-20	8.9
Oat straw	7,782	10-20	7.82
Rice straw	6,771	10-20	16.2
Rice hull	6,943	10-20	18.34
Switchgrass	7,744	10-20	10.05

Chemical composition, and therefore heat content, varies by plant component and biomass type. For example, the relative proportions of carbohydrates and other hydrocarbons vary between the two types of woody biomass: softwoods and hardwoods. Carbohydrates carry lower heat content (6,000 to 7,000 Btu/lb) than the other hydrocarbons in organic matter (such as lignin at 10,000 to 12,000 Btu/lb)[71] but are easier to hydrolyze into higher-value fuels and chemicals in fermentation processes than other hydrocarbons. Softwoods generally contain a higher percentage of volatile hydrocarbons, in the form of gums and resins, than do hardwoods. As a result, softwoods often, but not always, have higher heat content than hardwoods. In addition, bark often has higher lignin content than wood, which is one reason why its HHV is higher than wood of the same species.

Fuels with low heat content increase feedstock transportation costs per unit of usable thermal energy, thereby affecting the economics of biomass power generation. While it may be possible

[70]M. Reed, L. Wright, R. Overend and C. Wiles, *CRC Handbook of Mechanical Engineering* (Frank Kreith, Ed., CRC Press, Inc., 1998), Section 7 – Energy Resources, p. 26.
[71] Richard Elander, Pretreatment R&D Team Leader, NREL Division of Biotechnology for Fuels and Chemicals (telephone interview, Sept.11, 2002).

to pay less per ton for a feedstock with a lower HHV, it is likely to cost the same amount to transport a ton of low-energy fuel as it would to transport a ton of high energy-density material. In addition, the energy content of biomass fuels per unit volume can increase feedstock quantity requirements for combustion and gasification. This affects storage, handling and processing needs and the sizing of boiler and gasification systems. For example, using biomass fuels with low energy densities per unit volume may require a larger boiler vessel to achieve the same heat output as a boiler system run with a biomass fuel that has a higher energy density.

8.1.4 Chemical Composition

The chemical characteristics of biomass affect a variety of different processes. The chemical composition of the organic component of plant biomass is particularly important for microbial fermentation, pyrolysis and gasification. The non-combustible constituents of biomass supplies greatly affect biomass combustion processes. The overall chemical constituents are similar for most plant materials. Plant cell walls consist of water and complex carbohydrates, particularly cellulose and hemicellulose. Lignin is a non-carbohydrate plant component, the highly cross-linked polymer "mortar" that binds the plant-cell bricks together to add to the plant's structure as it matures. The cellulose, hemicellulose and lignin portions of the vegetable matter in terrestrial plants are also referred to as the *lignocellulosic complex*. These components along with proteins, gums and resins, and ash-forming minerals make up the plant's chemical structure.

The relative proportions of cellulose, hemicellulose and lignin vary widely in proportion between softwoods, hardwoods and herbaceous plants. Woody plants typically consist of about 50% cellulose, 25% hemicellulose, 25% lignin and trace amounts of ash-forming minerals. Herbaceous plants may contain about 40% cellulose, 25% hemicellulose, 15% lignin, 5% minerals and 15% proteins and resins.[72] The chemical composition of biomass feedstocks varies according to plant type but also by plant part (i.e., leaves, twigs, bark, stems and roots). Variation in the proportion of different plant types and plant part components affects a variety of biomass conversion processes.

Hardwood tree species tend to contain more hemicellulose and less lignin than softwoods. Grasses contain more volatile compounds in the form of proteins, fats and resins than other herbaceous and woody plants. Table 8-3 represents typical proportions of the primary organic components and ash content of several tree and crop varieties.

[72] Klass, *Biomass for Renewable Energy, Fuels, and Chemicals* (Academic Press, 1998), pp. 80-85.

Table 8-3. Abundance of chemical components in biomass

Category	Chemical Composition (wt%)				
	Volatiles	Ash	Lignin	Cellulose	Hemicellulose
Softwoods	0-5	0.5	25-35	40-45	25-28
Pine	0.7	0.5	34.5	40.4	24.9
Hardwoods	0-5	1	15-25	40-50	25-40
Poplar	1	2.1	25.6	41.3	32.9
Cereals	10-20	3-12	14-18	30-45	22-30
Barley straw	-	4.1	16.4	42.4	22.7
Wheat straw	-	8.3	16.2	33.5	25.4
Oat straw	-	5.3	14.7	35.1	24
Flax	-	8	2.2	71.2	18.6
Cotton	-	0.1	-	99.9	-

Non-combustible Components

The chemical characteristics of cellulose biomass are particularly important in combustion processes. Therefore, these characteristics are important to the decision process for choosing combustion technologies. While energy content is affected by the carbohydrate content in the plant material, the non-combustible fraction is particularly important for combustion because of operational issues associated with boiler efficiency, boiler slagging and fouling, erosion and corrosion, combustion instability and particulate carryover.

The amount of boiler slagging and fouling largely depends on the fusion temperature of the ash and the abundance and composition of ash-forming minerals. Slagging occurs when alkaline deposits accumulate or ash clumps together on the surfaces inside boilers. Alkalis such as sodium (Na) and potassium (K) are the primary causes of boiler slagging and typically have low melting points, reducing the ash fusion temperature. High alkalinity also causes fouling and slagging in stoker type boilers and agglomeration in fluidized bed combustors (consumption of fluidized bed material along with biomass fuels). Typically, agricultural residue has higher alkalinity than does wood residue.

The value of pounds of alkali per million Btu (lb/MMBtu) can be used as an indicator to estimate the risk of boiler slagging and fouling problems. Research indicates that biomass fuels with alkali contents below 0.4 lb/MMBtu are not likely to cause slagging problems.[73] Consequently, biomass feedstocks with high alkalinity are often blended with other fuels to reduce alkali concentrations to control fouling and slagging problems.

The minerals that combine to form ash have no energy value, so the HHV of a feedstock generally decreases as the ash content increases, reducing boiler efficiency. The ash content of a biomass feedstock should be analyzed to assess these impacts and estimate the amount of ash requiring disposal. Usually, clean softwood and hardwood fuels contain only trace amounts of ash-forming minerals, but cereal straws such as rice straw may have ash contents above 15% to 20%. Silica (SiO_2) is an abundant ash-forming mineral in crop residues that is abrasive, buffers acid reactions in pretreatment processes, adds to slagging problems in boilers.[74] Because the abundance of ash-forming minerals varies widely between woody and herbaceous plants and

[73] T. Miles et al., *Alkali Deposits Found in Biomass Boilers, Vol. II* (http://www.trmiles.com/alkali/alkali.htm Sandia National Laboratory and NREL, NREL/TP-433-8142 and SAND96-8225, February 1996), pp. 198-200.
[74] Ibid.

among plant components such as bark, leaves and stems, full characterization of the feedstock will ensure appropriate conversion process design.

Table 8-2 indicates typical ash contents for the residue of various trees and crops. Table 8-4 shows the mineral composition of the ash for several representative feedstocks. The presence of chlorine in the cereal straws should be noted. Research indicates that chlorine plays an important role in alkali release during combustion by exacerbating slagging.[75] High chlorine levels in oat straw, coupled with high sodium and potassium content, reduces the value of oat straw as an important fuel source for direct combustion unless it is blended with other, low-chlorine and low-alkali fuels.

Table 8-4. Mineral composition of the ash content of biomass materials

Material	Mineral Composition (wt%)														
	CO_2	Na_2O	K_2O	Cl	MgO	CaO	SrO	BaO	Al_2O_3	Fe_2O_3	SiO_2	TiO_2	Mn_2O_4	P_2O_5	SO_3
Pine	-	0.44	2.55	-	0.44	49.2	-	-	4.5	3.53	32.5	0.4	-	0.31	2.47
Poplar	14	0.18	20	-	4.4	47.2	0.13	0.7	0.94	0.5	2.59	0.26	0.14	5	2.74
Barley straw	6.2	1.15	30.2	4.5	2.15	11.3	-	-	0.4	0.45	42	-	-	3.7	2.85
Wheat straw	2.52	0.78	21.2	3.49	2.12	6.02	-	-	0.78	0.45	49	0.07	-	2.59	3.74
Oat straw	6.7	7.52	31.8	13.1	1.72	6.9	-	-	0.61	0.42	16.9	-	-	1.77	2.97
Switchgrass	-	0.1	15	-	2.6	4.8	0.04	0.22	0.45	0.45	69.9	0.12	0.15	2.6	1.9

It is important to analyze the sulfur content of the feedstock to estimate the amount of sulfur oxides (SO_x) likely to occur in fuel emissions. In addition to polluting the atmosphere, sulfates form deposits on boiler convection tubes, contributing to slagging problems. Overall, biomass has lower sulfur content and particulate emissions than coal, so biomass utilization benefits the environment by reducing the emissions of SO_x and ash associated with coal-fired boilers.

8.2 Ethanol Yields

The variations in organic composition of biomass require thorough consideration to obtain high product yields from a microbial conversion process. In fermentation processes, the lignocellulosic complex is naturally resistant to hydrolysis, so woody and herbaceous biomass often requires significant preparation and pre-treatment. During pre-treatment, weak acids may be used to dissolve and hydrolyze the hemicellulose, leaving a solid residue of cellulose and lignin. Next, the cellulose may be separated and reduced through enzymatic hydrolysis, leaving behind the insoluble lignin. The lignin may then be removed, dried and burned to provide heat for the process. After the cellulose and hemicellulose are hydrolyzed to simple sugars, microbial conversion uses yeast or bacteria to ferment the sugars, converting them to ethanol, methane or other chemicals.

Cellulose and hemicellulose are composed of different types of sugars that possess different chemical properties. For example, the primary sugar component of cellulose is glucose, a type of hexosan (or 6-carbon sugar). Hemicellulose is primarily xylose, which is a type of pentosan (or

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[75] D. Dayton and T. Milne, "Laboratory Measurements of Alkali Metal Containing Vapors Released During Biomass Combustion," *Applications of Advanced Technology to Ash-Related Problems in Boilers: Proceedings of the Engineering Foundation Conference* (Engineering Foundation, July 1995), pp. 161-185.

5-carbon sugar). As a result, the cellulose and hemicellulose must be extracted and hydrolyzed through separate processes. Furthermore, different microbes specialize in fermenting specific sugars; so different fermentative organisms are often needed to convert the hexosans and pentosans into fuel to achieve a high product yield. Hydrolysis of the holocellulose (the collective term for cellulose and hemicellulose) also produces varying amounts of mannose, galactose and arabinose sugars, depending on the types of plants in the feedstock.

Typical sugar proportions are shown as they occur in several representative tree and crop residues in Table 8-5. Sugars require specific enzymes to convert each of them into ethanol and other products. To maximize product yield from a microbial conversion process, it is important to analyze the sugar composition of the feedstock and tailor the enzymes used in the conversion process to optimize fermentation of the specific sugar constituents according to their relative proportions.

Table 8-5. Proportions of sugars, lignin and ash in several biomass types

Material	Biomass Composition (wt%)							
	Volatiles	Ash	Lignin	Glucan	Mannan	Galactan	Xylan	Arabinan
Softwoods	0-5	0.5	25-35	40-50	8-12	0-1	5-15	1-3
Pine	-	0.4	29.5	46.5	11.7	-	8.9	2.4
Hardwoods	0-5	1	15-25	40-50	4-6	1	15-20	2
Poplar	-	0.5	18.1	49.9	4.7	1.2	17.4	1.8
Cereals	10-20	3-12	14-18	32-40	0-1	0-2	15-22	2-4
Barley straw	-	10.8	13.8	37.5	1.3	1.7	15	4
Wheat straw	13	9.3	18.2	36.2	0.3	1.5	19.1	2.6

Research has focused on microbes that can rapidly generate high product yields from xylose and glucose, the primary sugar constituents in commonly available biomass feedstocks. Most fermentative organisms specialize in digesting particular sugars, and few produce the enzymes needed to directly ferment xylose or arabinose. Recently, several strains of yeast and bacteria have been genetically engineered to digest the sugar components of both cellulose and hemicellulose.[76] Yeast tends to be a very robust organism in ethanol conversion processes, but bacteria, which have the potential to be more efficient, are more susceptible to weak acids and other feed stream toxins such as chemical extractives. Softwoods evolved higher levels of gums and resins that inhibit fungal or bacterial growth. As a result, softwoods and hardwoods usually require distinct enzymatic or microbial conversion processes for optimal yields.

In the conversion of cellulose to ethanol, the approximate ethanol yield per ton of feedstock is a function of three variables: the weight fraction of holocellulose in the feedstock, the fraction of cellulose in the total carbohydrates and the fraction of total carbohydrates converted to ethanol.[77] Figure 8-1 illustrates the relationship between these factors and the estimated theoretical ethanol yield where the ratio of cellulose to hemicellulose is assumed 2:1.

[76] J. McMillan, "Hemicellulose Conversion to Ethanol," *Handbook on Bioethanol: Production and Utilization* (C. Wyman, Ed., Taylor & Francis, 1996), p. 288-89.
[77] C. Wyman, "Economic Fundamentals of Ethanol Production from Lignocellulosic Biomass" (American Chemical Society, 1995), pp. 278-79.

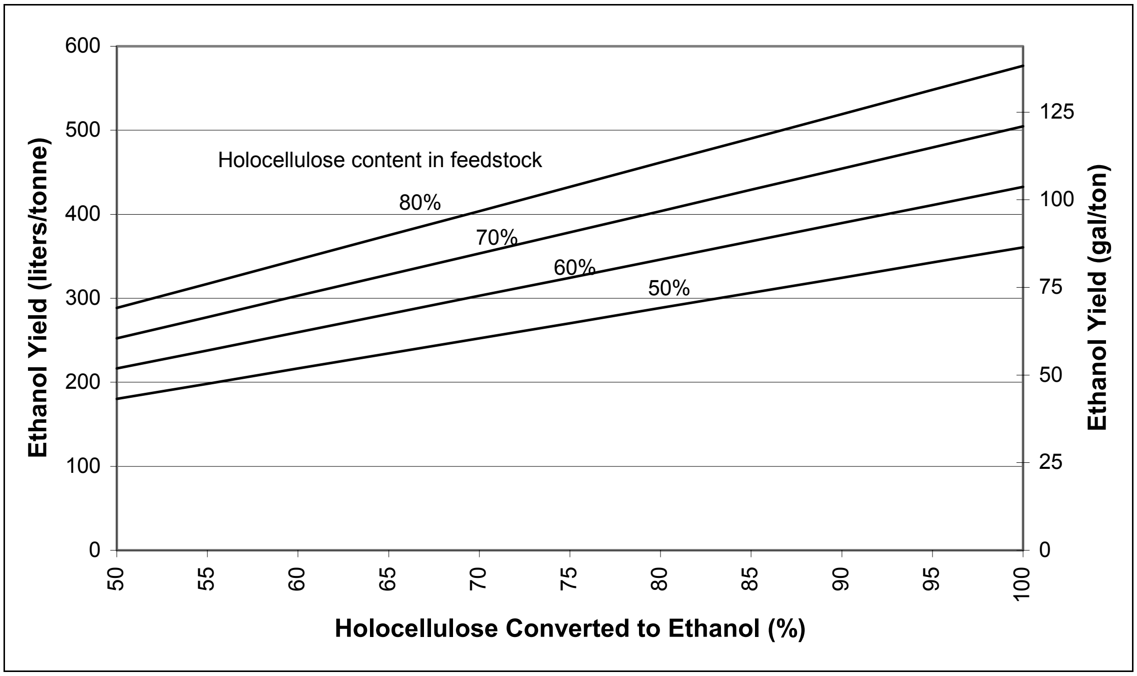

Figure 8-1. Volumetric ethanol yield per weight of feedstock

For example, if the feedstock contains 70% holocellulose, of which 80% is converted to ethanol, then the estimated yield is about 95 gallons per ton. The fraction of cellulose in the total carbohydrates tends to have a minor effect on ethanol yield in this process. Lignin is insoluble and is left behind as a solid residue after chemical and microbial conversion. The lignin is not easily reduced or fermented and is sometimes wasted, but it has similar heat content to low-grade coal (about 10,000-12,000 Btu/lb) and may be dried and burned as fuel in cogeneration systems. Assuming that most of the remaining 30% of the feedstock in the above example is lignin, enough material can be burned to provide the heat and electricity to power the entire conversion process, as well as excess electricity that can be sold for additional revenue.[78]

Several methods have been developed to estimate the ethanol yield from a biomass feedstock. Charles Wyman describes the method used to produce the plot in Figure 8-1 that estimates the net ethanol yield based on the ratio of cellulose to holocellulose, the weight fraction of holocellulose in the feedstock and the percentage of holocellulose converted to ethanol.[79] NREL developed another method that estimates the total theoretical ethanol yield according to the dry weight percentages of the sugar components in the feedstock.[80]

Table 8-6 summarizes the ethanol yields in gallons per ODT (gallons/ODT) calculated by these methods using the data from Table 8-3 and Table 8-5. The theoretical yield assumes 100% conversion of the feedstock carbohydrate content. Actual yield may be anywhere from 60% to 90% of the theoretical yield depending on the feedstock and the design of the conversion

[78] Wyman, 277.
[79] Wyman, 278-79.
[80] U.S. DOE Office of Transportation Technologies, *Theoretical Ethanol Yield Calculator* (http://www.ott.doe.gov/biofuels/ethanol _calculator.html, September 24, 2002).

process. Lab results indicate that ethanol yields can be expected in the 75% to 80% range for a well-designed process.[81]

Table 8-6. Theoretical biomass ethanol yields calculated from carbohydrate content

Wyman method	Cellulose (wt %)	Hemicellulose (wt %)	Theoretical ethanol yield (gallons/ODT)	75% of theoretical yield (gallons/ODT)
Pine	40.4	24.9	113	84.7
Poplar	41.3	32.9	128.6	96.4
Barley straw	42.4	22.7	112.5	84.4
Wheat straw	33.5	25.4	102	76.5

NREL method	Glucan (wt %)	Mannan (wt %)	Galactan (wt %)	Xylan (wt %)	Arabinan (wt %)	Theoretical ethanol yield (gallons/ODT)	75% of theoretical yield (gallons/ODT)
Pine	46.5	11.7	-	8.9	2.4	120.6	90.5
Poplar	49.9	4.7	1.2	17.4	1.8	130.4	97.8
Barley straw	37.5	1.3	1.7	15	4	103.6	77.7
Wheat straw	36.2	0.3	1.5	19.1	2.6	104.1	78.1

The yields calculated by the two methods cannot be directly compared here because the data come from different sources. In practice, yields will likely be lower than shown here. Research conducted by NREL, indicates that ethanol yields up to 70 gallons/ODT of clean pine wood can be obtained using a two-stage dilute acid hydrolysis process to extract and reduce the carbohydrates. That number drops to 60 gallons/ODT for pre-treated forest thinnings, and only 40 to 50 gallons/ODT for hogged thinnings. On the web page for NREL's ethanol yield calculator, a theoretical yield of 81.5 gallons/ODT is listed for softwood forest thinnings, or a practical yield (75% of theoretical yield) of about 61 gallons/ODT.

[81] Richard Elander, Pretreatment R&D Team Leader, NREL Division of Biotechnology for Fuels and Chemicals, telephone interview, Sept. 11, 2002.