



Assessing the Economic Availability of Woody Biomass

Matthew Langholtz, Douglas R. Carter, & Richard Schroeder

This document describes how Wood to Energy Outreach Program researchers assessed the economic availability of biomass resources in 28 communities across the thirteen southeastern states. This approach was taken to be able to apply nation-wide forestry data anywhere in the U.S. For instructions of a simplified approach to assessing the availability of biomass using site-specific information, see the Do-It-Yourself Supply Curves in this appendix and at <u>http://www.interfacesouth.org/woodybiomass</u>.

Biomass (i.e., plant material), including urban wood waste, logging residues, and forest thinning, can be used to generate renewable energy, reduce greenhouse gas emissions, improve forest health, and provide economic benefits to rural communities. The feasibility of bioenergy (i.e., energy generated from biomass) projects depends largely on the availability of woody biomass resources. More specifically, it is the economic availability, or total delivered price for a given quantity, rather than just the physical availability, that is relevant to the development of bioenergy projects. A simple way to express the economic availability of a resource is with a supply curve. Here we describe supply curves and how we developed biomass resource supply curves for communities in the thirteen southeastern states.

Supply Curves

A supply curve is a basic economic tool used to express the price of a resource at a given quantity of demand. For example, Figure 1 illustrates a hypothetical woody biomass resource supply curve. Quantity Q_1 can be generated at marginal price P_1 from urban wood waste, which is the cheapest resource. If biomass demand is increased due to higher levels of power generation capacity, more costly woody biomass resources such as logging residues might then be utilized to supply quantity Q_2 at price P_2 . A more complex supply curve might include other available resources and would account for transportation cost in ranking the economic availability of these resources of different types at different travel times.

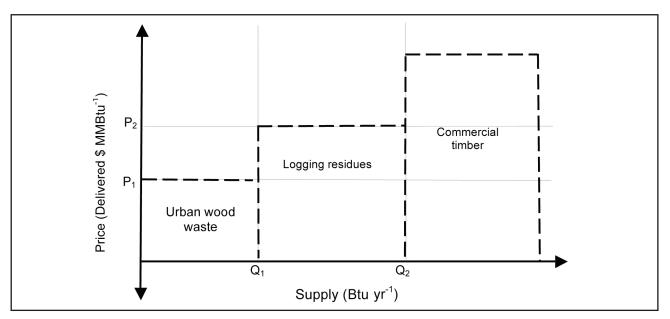


Figure 1. Hypothetical supply curve illustrates woody biomass resource categories.

The total cost for biomass depends on how biomass is actually purchased locally. If utilities offer a premium price for biomass resources that are more expensive and/or farther away, the total cost to the utility to meet a specified generation capacity is calculated as the area under the curve, or the sum of price multiplied by quantity for each resource category employed. In Figure 1 under these conditions, the calculation to purchase Q₂ with price discrimination is $(Q_1 * P_1) + (Q_2 * P_2)$. However, some utilities may not be able or willing to differentiate between different biomass resources that have different costs. If utilities cannot vary the price according to the resource, the total price to acquire a given quantity is the maximum price times the total quantity. In the example below, this calculation to purchase Q_2 is $P_2 * Q_2$, which would result in a higher total cost to the utility.

Constructing biomass supply curves requires information about production costs and the physical availability of resources. Following we describe how we calculate costs, determine the physical availability and geographic distribution of biomass, and create biomass resource supply curves to assess the economic availability of biomass resources.

Cost Calculations

The delivered cost of woody biomass can be defined as a sum of procurement (i.e., the amount paid to buy the wood), harvest, and transportation costs. We use the cost assumptions shown in Table 1, and calculate transportation cost as a function of haul time. More details of our assumptions are shown on page 6 and in a forthcoming USDA Forest Service General Technical Report. Haul times are calculated using ArcGIS Network Analyst extension as described in Box 1 and in ArcUser Magazine, October - December 2006, available at www.esri.com/ news/arcuser/index.html. We assume haulers drive the speed limit on the fastest road available to them, calculate total transportation times for the area of interest, and increase haul times (and thus costs) by 25 percent to account for operational delays. Transportation costs could alternatively be calculated by haul distance rather than time, or transportation cost could be assumed uniform for each woody biomass resource within a maximum haul radius. The next step in constructing the woody biomass resource supply curve is to determine what quantity of biomass is available in each woody biomass resourcehaul time category for a given community.

We sum procurement, harvest, and transportation costs to calculate the total delivered cost of each woody biomass resource within a given haul time at 15-minute increments as shown in Table 1. By ranking these resourcehaul time categories from lowest cost to highest cost, the progression of most to least economically available woody biomass resources is estimated (Table 2). Under these cost assumptions, logging residues requiring a oneway haul up to 45 minutes are cheaper than the nearest pulpwood resources.

Table 1. Summary of Cost Assumptions for Three Woody Biomass Resources

	Urban Wood Waste	Logging Residue	Pulpwood						
\$/green US ton (\$/dry metric ton)									
Procurement cost	-15.00	1.89	6.89						
	(-27.56)	(3.31)	(14.33)						
Harvest and process	18.00	15.12	12.72						
	(33.07)	(26.46)	(26.46)						
Load and unload	1.24	1.18	0.92						
	(2.28)	(2.06)	(1.91)						
One-way haul (per hour)	3.72	3.54	3.12						
	(6.83)	(6.19)	(5.73)						
Example total delivered cost of a one-hour haul ^a	11.68	25.27	26.77						
	(21.45)	(44.21)	(54.16)						

*Equals the sum of two times the one-way haul cost and the remaining three cost categories. Assumptions for calculations are found on page 6.

Resource/Haul time category	Delivered cost (\$/dry US ton)	Delivered cost (\$/MMBtu)
Urban wood: 0-15 minutes	0.02	\$0.65
Urban wood:15-30 minutes	0.11	\$0.85
Urban wood: 30-45 minutes	0.16	\$1.05
Urban wood: 45-60 minutes	0.17	\$1.25
Logging residues: 0-15 minutes	0.09	\$2.03
Logging residues: 15-30 minutes	0.50	\$2.21
Logging residues: 30-45 minutes	0.97	\$2.39
Pulpwood: 0-15 minutes	0.24	\$2.56
Logging residues: 45-60 minutes	1.29	\$2.57
Pulpwood: 15-30 minutes	1.50	\$2.72
Pulpwood: 30-45 minutes	3.03	\$2.88
Pulpwood: 45-60 minutes	4.14	\$3.04

 Table 2. Wood Resources Ranked by Total Delivered Energy Cost

Physical Availability

In addition to production costs, information about the physical availability of resources is required to construct supply curves. We compiled county-level woody biomass resource information for all counties in the southern U.S. To estimate woody biomass quantities from logging residues and pulpwood, we accessed Timber Product Output (TPO) reports (http://srsfia2.fs.fed.us/php/tpo2/tpo. php) maintained by the Forest Inventory and Analysis (FIA) work unit of the USDA Forest Service, Southern Research Station (SRS). This database provides forest inventory and harvest information, including annual yields of logging residues and pulpwood at the county level. The TPO reports use the latest available FIA Inventory data as a baseline, which is then updated according to more frequent (about every 2-3 years) mill surveys. The 2003 TPO Report for Florida is used here. Logging residues includes TPOs annual non-growing stock removals reduced by 30 percent to exclude stumps and account for unavailable resources.

Because the pulpwood harvest identified in the FIA TPO report is currently used to produce pulp and paper products, not all of this resource is economically available for bioenergy. However, additional biomass is available from forest thinnings (Perlack et al. 2005, Condon and Putz 2007), which are not included in this assessment. Furthermore, southwide softwood and hardwood growth exceeds removals (Adams et al. 2003), indicating that more wood can be sustainably harvested. Recent trends of poor stumpage prices and loss of markets for forest products in the South may have reduced forest management activities (Smidt et al. 2005), which could be mitigated by providing additional timber markets.

We assume 0.111 dry metric tonnes (0.203 green tons) of urban wood waste per capita annually (based on Wiltsee 1998). This per capita estimate includes municipal solid waste wood from yard waste and tree trimming but excludes an additional 0.1 dry metric tonnes (0.2 green tons) per capita annually reported from industrial wood (e.g., cabinet and pallet production) and construction and demolition debris. We multiply this average annual per capita yield by county level 2005 U.S. Census population estimates (www.census.gov/popest/counties/) to estimate total annual county yield of urban wood waste. Assumptions of availability, wood densities, and energy content for all included woody biomass sources are shown in Tables 3 and 4. We then use the method described below to estimate what portion of these county-level resources are within each resource-haul time category for a given delivery point.

Supply Curve Construction

Given information regarding quantities, distribution, and procurement, harvest, processing, and transport costs for each woody biomass resource, supply curves can be constructed. Assuming homogeneous distribution of woody

biomass resources within counties (a necessary assumption given the FIA source data), we calculate the amount of woody biomass in each haul time category in each county, and summarize quantities available from each resource-haul time category for the area of interest. We assign total delivered costs for each resource-haul time category, and sort from least to most expensive (Table 2). Supply curves are then plotted where the x-axis is the cumulative total amount of woody biomass with each additional resource-haul time category and the y-axis is total delivered cost. Curves can be plotted as an Excel[©] scatter plot or by using the Macro Economic Supply Curve Chart Excel[©] add-in. We express units based on energy content of the biomass, though units could be expressed as mass. The steps in the supply construction are discussed in Box 1 and shown in the work flow diagram in Figure 2.

For more information see the "Community Economic Profiles" section and our other materials at <u>http://www.</u> interfacesouth.org/woodybiomass.

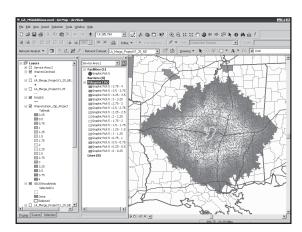
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- Chandrasekhar, T. 2005. ArcGIS Network Analyst tutorial. Redlands, CA: ESRI. 1-38.
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Box I. Steps in Supply Curve Construction

Assessing transportation cost based on haul time rather than distance accounts for road infrastructure in a woodshed. Haul times can be estimated by using GIS to account for speed limits assigned to U.S. Census Topologically Integrated Geographic Encoding and Referencing (TIGER) roads layers. Following is a summary of steps that can be used to assess haul times by generating service areas with ArcGIS[®] Network Analyst:

- 1. Identify delivery point (e.g., county centroid, generation plant).
- 2. Identify area of interest (AOI) to include the maximum potential extent of the woodshed. A 450 km (280 mile) radius includes more than a 4-hour one-way haul. Identify counties within the AOI.
- 3. Download U.S. Census TIGER roads shapefiles for the AOI from <u>http://arcdata.esri.com/data/tiger2000/</u> <u>tiger_download.cfm</u>. Merge the roads, define the projection (see Price and Coleman 2003), and re-project the merged roads layer. Keep all layers in the same projection.
- 4. Assign speed limits to each roads segment according to census feature class codes and calculate travel time (see Price and Price 2003). To account for expected travel delays, we increase calculated travel times by 25 percent.
- 5. Calculate service areas based on haul time using the ArcGIS Network Analyst Service Area Calculator (see Chandrasekhar 2005). We assess haul times based on 15-minute haul intervals, and assume the "ToBreak" field value for each haul time category. Export service area polygons to a shapefile.
- 6. Union the service area polygons to the county polygons and clip as necessary. Ensure the unioned shapefile is projected, add a "NewArea" field (float) and calculate areas of each feature.
- 7. Add a "ConCat" field (text) and concatenate the county name or "FIPS" field with the "ToBreak" field. Summarize the "ConCat" field including the average of the original area and the sum of the "NewArea" field.
- 8. Import the summarized *.dbf to a spreadsheet software such as Excel[®]. For each "FIPS-ToBreak" record, divide the "NewArea" by the original area to determine what percentage of each county is in each haul time category.
- 9. This percentage can be used to estimate what percentage of the woody biomass resource in each county resides in each haul time category. A Microsoft Excel Pivot Table can then be used to summarize the estimated total of each biomass resource in each haul time category.



Haul time categories are calculated from U.S. Census TIGER roads in ArcGIS Network Analyst[©].

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1350 x		4787-125		47757		Pulprood 125	Papyood	sv	Pulpwood-5'v/-4787	1,995	150		2,51
1351 x		4787-15		47757		Pulprood 15	Papyood	SV	Pulpwood-5'v/-4787	1,995	40		73
1352 x		4781-175	3%			Pulpvood 3.75	Papwood	54	Papeood-Sh/-4783	4,038	151	16.154	2,63
1353 x		4783-4	20%		4	Pulprood 4	Papyood	54	Pspvood-51/-4710	4,030	972		15,70
4354 x		4787-1		47357		Pulprood 1	Papwood	54	Palowood-5's/-4787	8	1	16.154	
1355 x		4787-125		47957		Pulpvood 125	Papwood	5V	Palewood-5%-4787				8
1356 x		4787-15		47957		Pulprood 15	Papwood	5V	Papwood-51/-4787		0	16.754	10
1357 x		4787-175	85		175	Pulprood 175	Papwood	5V 8V	Papwood-5%/4787	3	1	16.754	1
1358 x		4787-2		47367		Pulprood 2	Palprood	5V 8V	Papwood-51/-4787		0		14.21
1355 x 1360 x		4781-3.25	N TN	47351		Pulprood 325	Palpwood	5V 8V	Palprood-SV-4788	108,068	100	3.74	14,21
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382 7		47101-0.79	355	4730	110	Pulprood 4	Palprood	8W	Papeope-Syl-4788	101.068	38,007	8.64	613,87
1363 +		42103.2.25				Pulprood 275	Palprood	- 04 8M	Papeope-5v/4783	5,775	30		53.57
1384 +		4783-3	28%		- 610	Pulprood 3	Palprood	8¥	Papeope-St/4783	5,775	1200		27,47
1365 +		47183-325	385			Pulprood 325	Palprood	8W	Papeope-St/4783	5,775	2/14	8.54	35.8
1366 +		42103-029	265			Pulprood 35	Palprood	8W	Papeood-St/ 4783	5,775	1600	8.54	24,00
1387		42103-03	25			Pulprood 375	Palprood	8W	Pagerood-Styl 4783	5,775	380		6,0
1368		42102-4	- 10 50			Pulproot 4	Palprood	8W	Pagerood-Styl 47182	45		8.54	
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1770 -		(0)(3.0.25	10%	1822	1.05	Puterood 325	Palpacod	HV	Palmenod HV 822	21778	2,991		49.31
371 1		(0)23-2.5	265	1822		Puterood 25	Palmetod	HV	Palpapod-HV-800	21778	5.523		30.0
372 +		(0)23-275	24%			Pulpeood 275	Palpacod	HV	Palmenod HV-822	21778	7.51		121.32
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376 x		(6)57-4	25%	1957		Pulawood #	Palorecod	HV	Palpeopt HV-807	27.568	9562	8.54	152.65
1778 x		(0)53-2.25	25			Pulawood 225	Palorecod	HV	Palpeopt HV-8058	23.056	82		2.63
377 x		(0)53-2.5	17X			Pulpycod 25	Palowood	HV	Palpecod HV-8058	23.056	5,872	5.54	8182
379 x		(0053-2.75	26%			Pulpeood 275	Palowood	HV	Palpecod HV-8058	23.056	10,546	5.54	175.2
379 x		(0)53-4	22%			Pulpycod +	Palowood	HV	Palpeopd-HV-8058	20.096	9,920	5.54	8054
220 x		(0)75-2.25	05			Pulpycod 225	Palowood	HV	Palpeopd-HV-1075	4.128		5.54	22
221 x		00075-2.5	No.			Pulpwood 25	Pulpwood	HV	Pulpwood-HN-1075	4,03	671		10,54
222 x		00075-2.75	27N			Pulprood 275	Pulpwood	HV	Pulpwood-HN-1075	4,03	1,127	15.254	10,20
222 x		00075-4	20%			Pulprood 4	Pulpwood	HV	Pulpwood-HN-1075	4,03	1,164	16.154	10,47
204 x		00077-2.5	25	1077		Pulpycod 25	Pulpwood	HV	Pulpwood-HN-1077	29,292	512	16.154	14,75
395 x	17	00077-0.75	29%	1077	175	Pulpycod 2.75	Pulpwood	HV	Pulpwood-HN-1077	29,292	11,445	16.154	104,87
306 x		00077-4	23N	1077		Pulprood 4	Pulpwood	HV	Pulpwood-HN-1077	29,392	6,600	16.154	100,64
307 x	13	00073-4	IN	1079	4	Pulpwood 4	Pulpwood	HV	Pulpwood-HN-1073	23,392	2,454	16.154	29,80
300 x		00003-0	2%	1000		Pulprood 0	Papyood	HV	Pulpwood-HN-1093	38,032	534	16.154	9,61
309 x		00003-3.25	19%	1000		Pulprood 325	Papyood	HV	Pulpwood-HN-1093	38,032	5,674	16.154	91,65
1390 x		00003-3.5	32%	1000		Pulprood 3.5	Papyood	HM	Pulpwood-HN-1093	38,032	9,754	16.154	157,56
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The percentage of the area of each county in each haul time category is calculated and exported to Excel[®].

An Excel[®] Pivot Table is used to summarize the quantity of each biomass resource in each haul time category, and the costs of each product-haul time category are assigned. Product-haul time categories are sorted from least to most expensive, and supply curves are plotted.

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	Total	9,445	941	10,389	760	1,512	2,272	454	145	630	10,692	2,599	13,291	
Beldwin, AL	Softwood	19,777	1,256	21,033	876	2,310	3,196	506	49	554	21,160	3,613	24,773	
Baldwin, AL	Hardwood	3,617	412	3,029	679	1,012	1,691	465	203	660	4,962	1,626	6,100	
	Total	23,194	1,668	24,982	1,598	3,321	4,877	972	290	1,222	25,721	5,240	30,961	
Berbour, AL	Softwood	13,931	1,133	15,064	628	1,054	2,282	363	34	397	14,921	2,822	17,743	
Berbour, AL	Handwood	4,043	471	4,514	801	1,193	1,994	549	239	788	6,393	1,903	7,296	
	Total	17,974	1,604	19,578	1,429	2,847	4,276	912	273	1,185	20,314	4,725	25,039	
BRb, AL	Softwood	16,095	984	17,079	712	1,875	2,587	411	39	450	17,218	2,898	20,116	
BRb, AL	Handwood	3,903	394	4,377	776	1,157	1,933	532	232	764	5,292	1,782	7,074	
	Total	20,078	1,378	21,456	1,488	3,032	4,520	943	271	1,214	22,510	4,680	27,190	
Bourt AL	Softwood	5.025	436	5.462	227	600	827	132	12	144	5,385	1.047	6.433	

County level resource data are retrieved from FIA. Urban wood waste estimates are based on county population from the U.S. Census.

County level biomass resource data is multiplied by the proportion of each county in a given haul radius to estimate the proportion of a county's resources in each haul time category.

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256 x		4787-525		4/36/ A7507		Pulpycod 15	Papeood	5W	Papercology 4/%/ Delevand/St/4767	- 8	0	5.54	
354 x 357 x		4787-03		4/36/ A7507		Pulpycod 15 Pulpycod 175	Papeood	34	Papwood-GW-47%7 Palowood-GW-47%7	10	1	5.54	1
259 x		4782.0		A7507		Pulpycod 2	Palprood	5W	Paperon Print			5.74	-
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160 x	601	4786.25	10	A7101		Pulpycod 25	Palawood	GV/	Palmannet-Shir4788	100.060	11422	15 17.4	104.21
101 v	698	47105.1.25	375	A7101		Pulpycod 275	Palawood	GW	Palprope-GV-47101	100.060	40157	15 17.4	640.63
262 x	624	47101-4	25N	47321		Pulpycod 4	Palawood	5V	Palprope-GV-47101	101.068	20.897	15.254	\$12.57
292 x	692	47103-2.75	35	47102	2.75	Pulpyood 2.75	Palowood	5V	Palpeopd-SW-4782	5,775	20	15.274	50
264 x		47103-0		47122		Pulpwood 2	Pulpwood	sv	Pulpwood-GW-47103	5,775	1,791	16.154	27,47
365 x		47103-0.25				Pulpwood 225	Palpwood	5V	Palpwood-GW-47103	5,775	2,174	16.154	25,8
366 x		47103-0.5				Pulpycod 25	Palpwood	5V	Palpwood-GW-47103	5,775	1,400	16.154	24,00
367 x		47103-0.75		47102		Pulpvood 2.75	Pulpwood	sv	Pulpwood-GW-47103	5,775	200	16.154	6,13
360 x		47107-4		47907		Pulprood 4	Pulpwood	sv	Pulpwood-GW-47107	45	2	16.154	3
369 x		00003-0	2%	1022		Pulprood 2	Pulpwood	HV	Palpwood-HN-1003	21,776	290	16.154	6,43
370 x		00003-0.25	MX	1000		Pulprood 225	Pulpwood	HV	Papeood-HN-8003	21,776	2,991	16.154	40,16
371 x		00003-0.5	26%	1000		Pulprood 25	Pulpwood	HV	Papeood-HN-8003	21,776	5,570	16.154	90,03
372 x		00003-0.75	34%	1000		Pulprood 2.75	Pulpwood	HV	Papeood-HN-8003	21,776	7,51	16.154	121,32
370 x		00003-4	23%	1022		Pulprood 4	Papwood	HV	Pulpwood-HN-8003	21,776	4,540	16.154	79,92
274 x 275 x		00057-3.75	0N 25N	1057		Pulprood 3.75 Pulprood 4	Pulpwood Pulpwood	HV HV	Pulpwood-HV-1057 Pulpwood-HV-1057	27,568	0,826	16.254	40,00
376 x		00053-0.25	20%	1057		Pulpycod 225	Papwood	HIV	Pupwood-HV-8058	20,096	9,962	16.154	2.63
376 x 377 x		00053-3.25	TN IIV	1050		Pulpycod 25	Papwood	HV	Pupwood-HV-8058	28,096	5.872	16.154	2,63
370 x		00053-1.75	364	1050		Pulpycod 275	Palprood	HV	Palprood-HV-1053	20,004	10.146	10.74	125.2
170 x		00534	325	1050		Pulpycod 4	Palprood	HV	Palprood-HV-1053	31,056	9,100	10.74	150.54
390 x		00075-0.25	0%	1075		Pulpycod 225	Palprood	HV	Palprood-HV-1075	4.21		10.74	22
331 7	13	00375-3.5	10	1075		Pulpycod 35	Palayood	HM	Palpropd-HV-8075	4.121	671	16 754	10.14
382 x	14	00075-0.75	27N	1075		Pulpycod 2.75	Palayood	HM	Palpropd-HV-8075	4.121	1127	16.254	10,20
x C60		00075-4	20%	1075	4	Pulprood 4	Papeood	HV	Papeood-HN-1075	4,128	U44	16.154	10,47
354 x	16	00077-3.5	3N	1077		Pulprood 35	Palpwood	HV	Pulpwood-HN-8377	29,092	10	16.154	14,75
305 x		00077-3.75	39%	1077	175	Pulprood 3.75	Palpwood	HV	Pulpwood-HN-8377	23, 392	1,445	16.154	104,07
306 x		00077-4	23%	1077		Pulprood 4	Palpwood	HN	Pulpwood-HN-8377	29,392	6,600	16.154	100,04
387 x		00073-4	TN	1079		Pulprood 4	Papwood	HV	Pulpwood-HN-8073	23,392	2,454	16.154	39,80
355 x		00093-3	2%	1053		Pulprood 3	Papwood	HV	Palpwood-HN-8093	38,032	534	16.154	9,61
399 x		00003-3.25	19%	1053		Pulpvood 325	Papwood	HV	Palpwood-HN-3093	38,032	5,674	16.154	91,65
330 x		00003-3.5	32%	1053		Pulprood 3.5	Papyood	HV	Palpwood-HW-9093	30,032	0,754	16.854	157,56
331 x		00003-3.75	37%	1053		Pulprood 3.75	Palpwood	HV	Palpwood-HW-9093	30,032	1,230	16.154	101,41
A F H		tout \ Cnt	- W	Prest		Putramed &	Palmannel	He l	Palmanut J-023391	20.07	2 892	30 PH	1

Figure 2. This work flow diagram illustrates the resources and steps used in woody biomass resource supply curve construction.

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Authors

Matthew Langholtz, Postdoctoral Research Associate and Douglas R. Carter, Professor, are with the School of Forest Resources and Conservation, University of Florida, Gainesville, FL. Richard Schroeder is President of BioResource Management, Inc., Gainesville, FL.

Variable/attribute	Logging residues	Urban Wood Waste	Pulpwood	
Load and unload time per load (hours)	0.50	0.50	0.50	
Load and unload cost per load (\$)	\$25.00	\$25.00	\$25.00	
Green tons per load	23.0	22.0	28.0	
Load and unload cost per green ton (\$)	\$1.09	\$1.14	\$0.89	
Moisture content (green weight basis)	37%	40%	47%	
Ash content	5%	5%	2%	
Load and unload cost per dry ton (\$)	\$1.87	\$2.07	\$1.73	
Haul cost (\$/hour/load)a	\$75.00	\$75.00	\$75.00	
Haul cost (\$/hour/green ton)	\$3.26	\$3.41	\$2.68	
Two-way haul cost (\$/hour/dry ton)	\$11.24	\$12.40	\$10.40	
MMbtu/dry ton	15.58	15.58	16.15	
Harvest and process (\$/dry ton)	\$24.00	\$30.00	\$24.00	
Procurement cost (\$/dry ton)	\$3.00	\$(25.00)	\$13.00	
Quantity assumed recoverable	90%	60%	100%	

Table 3. Operational Assumptions

Table 4. Density Assumptions

	Gram cubic cm-1 (Pounds cubic foot-1):
Hardwoods	0.513 (32)
Softwoods	0.481 (30)



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