Assessing Ohio's Biomass Resources for Energy Potential Using GIS

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REVIEW DRAFT

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Abstract

This recently completed AEDE study funded by Ohio DOD involves a geo-referenced inventory by county of Ohio biomass resources for energy. Categories include forest and crop residues, livestock manure, municipal solid waste and food processing waste. This is an update and expansion of an earlier (1982) inventory of biomass by Hitzhusen et al. It also disaggregates and expands a study by Walsh et al. in 2000 which ranked Ohio 11th among the 50 states in total biomass availability. By estimating and geo-referencing the sustainable quantities of various categories of biomass for energy by county, it is possible to identify the spatial concentrations of various biomass renewable energy feedstocks that may be economically viable for various processes for conversion. These conversion processes in turn have implications for environmental improvement and reduced dependence on foreign oil imports.

A better understanding of the technical and economic pros and cons of the most promising conversion processes will be required along with further data collection and refinements of this inventory (particularly the food processing waste subset) before detailed policy recommendations can be made. However, this study is hopefully a good start toward that goal and should provide direction and focus for future analysis and recommendations for a more renewable and sustainable energy and environmental future for Ohio.

1. Rationale and objectives

Bringing air quality into compliance with standards set by the US Environmental Protection Agency (EPA) is a critical issue in many metropolitan regions across the USA. In addition, for energy security purposes, the production of biofuels from agriculture and forestry sources has been considered for many years in the US, particularly after the 1970's energy crisis. Biomass is important in connection with possible global warming. Through photosynthesis, biomass removes carbon from the atmosphere, thus reducing the amount of atmospheric carbon dioxide, a major contributor to global warming. When biomass is burned to produce energy, the stored carbon is released, but the next growing cycle absorbs carbon from the atmosphere once again. This "carbon cycle" offers a unique potential for mitigating some global warming, in contrast to burning fossil fuels, a stock resources. These issues have led to calls for efforts to inventory, collect and extensively convert in various ways biomass renewable resources to energy sources. In fact, before investing time and money in technologies for using a new resource, information is needed about the location, form and availability of the resource.

As part of a major OSU biomass research initiative in the late 1970s and early 1980s in Ohio, a biomass feedstock inventory by county was completed in 1982 (Hitzhusen, et al). This earlier effort was intended to develop a fairly conservative set of first approximations of annual wood energy, crop residue, livestock manure, and municipal solid waste energy potential. With the exception of methane from livestock manure, all of these earlier estimates were based on sustainable biological not economic potential. For example, the crop residue estimates assumed sufficient residue left on the land to control soil erosion at acceptable levels. In addition to this inventory, research was conducted on the technical and economic feasibility of co-combustion of several types of biomass including crop and forest residue and municipal solid waste with high sulfur coal to produce electricity and lower sulfur emissions (eg, Hitzhusen and Abdallah, Gowen and Hitzhusen and Hitzhusen and Luttner).

Recent studies illustrate that Ohio has a relatively large biomass resource potential. Among the 50 states, Ohio ranks 11th in terms of herbaceous and woody biomass (See Table 1.1) and 4th in terms of food waste biomass (U.S. Bureau of Economic Analysis). As a result, using renewable biomass fuels in Ohio could lead to an estimated 27.6 billion kWh of electricity, which is enough to fully supply the annual needs of 2,758,000 average homes, or 64 percent of the residential electricity use in Ohio.

Use of biofuels can reduce dependence on out-of-state and foreign energy sources, keeping energy dollars invested in Ohio's economy. Biomass energy crops can be a profitable alternative for farmers, which can potentially complement, not compete with, existing crops and provide an additional source of income for the agricultural industry. Biomass energy crops may be grown on currently underutilized agricultural land. In addition to rural jobs, expanded biomass power deployment can create high skill, high value job opportunities for utility and power equipment, and agricultural equipment industries.

A study by Walsh et al. (2000) estimates the quantities and prices of biomass feedstocks that could be available on an annual basis for each state in the US. In their study, they classify biomass feedstocks in five general categories: urban wood wastes, forest residues, mill residues, agricultural residues, and dedicated energy crops. They base on Walsh et al. (1998) to estimate the biomass prices and quantities. The figures presented below are given for Ohio by anticipated delivered price and categories of biomass feedstocks. The estimated quantities represent the potential annual biomass feedstocks at delivered price. The prices include collection, harvesting, chipping, loading, hauling, unloading costs, a stumpage fee, and a return for profit and risk. According to the table, more than 18 million dry tons biomass could be available annually in Ohio at prices less than $50 dry ton delivered. Based on this quantity and these prices, Ohio ranks 11th among the 50 US states.

Table 1.1: Ohio Estimated Annual Cumulative Biomass Feedstocks Quantities (dry tons), by Categories and Delivered Price.

	<$20/ dry ton delivered		<$30/ dry ton delivered		<$40/ dry ton delivered		<$50/ dry ton delivered	
	Qty	**Rank**	**Qty**	**Rank**	**Qty**	**Rank**	**Qty**	**Rank**
Urban wood waste	744,518	11	1,240,864	11	1,240,864	11	1,240,864	11
Forest residues	-	-	232,000	32	435,000	32	430,100	32
Agricultural residues	-	-	-	-	7,634,476	9	7,634,476	9
Energy crops	-	-	-	-	3,808,089	9	9,657,080	7
Mill residues	-	-	-	-	-	-	-	-
Total biomass	**744,518**	**12**	**1,472,864**	**24**	**13,018,429**	**9**	**18,962,520**	**11**

Source: Walsh et al. (2000)

However, the estimates provided in table 1.1 are at an aggregate level. Nothing is revealed about the distribution and the location of these biomass feedstocks within the state. It would be interesting to have information on what part of the state is more endowed with a particular type of biomass resource in order to identify the potential source and demand points. An updated biomass inventory by type, amount and spatial or geographic location (e.g., county) is a necessary first step for determining the current and future energy potential of biomass in Ohio. This in turn, will facilitate research on the technical and economic feasibility of alternative conversion technologies such as combustion, anaerobic digestion, etc… and end products such as electricity, methane, etc. The estimates from 1982 are updated for forest residues, municipal solid and livestock wastes and both updated and revised in the case of crop residue in light of more recent concerns with carbon sequestration. In addition, food processing waste which was not included in the 1982 inventory is included in this current inventory.

2. Approach

Methods of collecting data on biomass vary depending on the type of biomass. Whereas wood and crop residues, municipal solid and livestock waste can be inventoried largely from secondary data sources, the food processing wastes requires primary data collection and sampling of this fairly broad waste or resource category. Although county is used as unit of data source collection, as done in previous studies, the analysis in this study is done threefold (except for the food processing wastes due to data limitation): the whole Ohio state, by region and by county. Map 2.1 shows the distribution of Ohio counties by regions. The composition of each region is based on TravelOhio.com. All computation and estimation were done using the Excel application software. While visualization of the results from state and regional level analysis can be done using two-dimensional figures, results from the county level analysis can best be visualized using maps showing all Ohio counties through geo-referencing. Herein lies the necessity of incorporating Geographic Information System (GIS) procedures in the analysis.

In fact, GIS provides a powerful way to combine data in a geographic framework to help answer such questions as what are the best sites for a biomass conversion to energy project involving one or more biomass feedstocks? What county or geographic area has more potential in a specific type of biomass? A GIS is a software database program that runs on personal computers. The key feature of a GIS is that it links the spatial location of an object (a county for example) with data and information that are associated with the object (different types of biomass for example). Any information that has a geographic location associated with it can be stored in a GIS and used to answer questions that have a geographical dimension. For example, where are the concentrations of wood waste within Ohio and thus the optimal location for installing a wood waste combustion or gasification plant?

The step to creating the biomass spatial database is threefold. First, the shape file[2] for county boundaries in Ohio was taken from http://dynamo.ecn.purdue.edu/~biehl/MRCSP.html. Second, an Access file (mdb format) was created from the Excel worksheet. Finally, the Access file was joined to the attributes table of the shape file. The advantage of this procedure is that any changes made to the Excel worksheet are automatically transmitted to the joined attributes table via the Access file. For the food processing wastes component of the study, data from the Harris Directory was then imported into the statistical package SAS in order to efficiently process and sort the data. The resulting SAS datasets were then exported into Excel spreadsheets and into ArcGIS, where the spatial characteristics of the data could be illustrated. As a result of the GIS analysis, in addition to figures and tables, maps are produced for each type of biomass. Simply looking at a map will provide preliminary or "first cut" answers to questions such as those above. Previous studies evaluating biomass potential have applied GIS (Block and Ebadian 2003, Graham et al. 2000). The methodology used in this study is similar to that implemented in these studies.

[2] Geographic Coordinate System used: GCS_North_American_1983
Datum: D_North_American_1983
Prime Meridian: 0

Map 2.1: Distribution of Ohio Counties by Geographical Unit

3. Crop residues

Crop residues represent a significant potential source of biomass in Ohio. They are defined as organic material remains left on the field after harvesting. Among the states, Ohio ranks 6th, 7th, and 10th, in terms of wheat, soybeans and corn production respectively in 2002. Table 3.1 presents, the annual average acreage for the two most important commodity crops in Ohio. Crop residues with relatively low carbon-to-nitrogen ratio decompose more rapidly. Compared with corn stover which has a carbon-to-nitrogen ratio 30:1 up to 70:1, soybeans have a carbon-to-nitrogen equals to 20:1 and thereby decompose in a very short time after harvest (Shomberg et al 1996). As a result, residues from soybeans are relatively uncollectable due to their rapid deterioration on the field and the small quantity generated. The majority of collectable crop residues is limited to wheat straw and corn stover. As a result, in this study, only corn and wheat are used to estimate the amount of crop residues potentially available for energy purposes. Corn stover includes stalks, cobs, husks, leaves and so on. Scientists have developed a pretreatment process to convert corn stover into ethanol which can be used to boost octane, reduce engine knock, and blend with gasoline to produce biofuels (Tally 2002). Crop residues can also be used in cogeneration facilities to produce electricity and steam. One advantage of using crop residues is that their production cost is already born in the cost of producing the grain or the marketable product. Consequently, using crop residues as biomass feedstock to produce ethanol or to generate electricity provides many benefits such as reducing dependence on imported fossil fuel, offsetting green house gases from fossil fuel and empowering the farmers and the rural communities and developing renewable energy sources, provided that soil productivity is maintained.

Table 3.1: Annual Average Acreage for Ohio Major Commodity Crops (1997-2003)

Crop	Acreage planted (000)	Acreage Harvested (000)	Yield per acre (Bu/Acre)	Production (1000 Bu)
Corn *	3,471	3,229	133	430,807
Wheat	1,060	1,014	67	67,636
Total	**4,531**	**4,243**	**-**	**498,443**
Source: http://www.nass.usda.gov/				

*: Corn for grain

Amount of crop residues left on the field after harvest is directly related to the quantity of grain produced, which in turn depends on crop yield and acreage harvested. Consequently, weather conditions and farmers' decision as to the number of acres to plant are critical in determining the amount of crop residues. The residue to product ratio (RPR) method is often used to quantify the amount of crop residues left on the field after harvest. In the literature, different RPR values have been reported for the same crop. According to Metzger and Benford (2001), crops generate 1.5 pounds of residue for each pound of harvested material. Myers (1992) and Samples and McCuctheon (2002) point out that 50-60 pounds of corn residues are generated for each bushel of corn produced. Other researchers have used different ratios, which are shown in table 3.2. Still, a widely accepted formula used in estimating crop residues is given by equation (1). Nelson (2002) for example, uses this formula to estimate corn stover and wheat straw in the Eastern and Midwestern US. In this study, gross amount of crop residues is estimated using equation 1 since it involves crop yield which is a very important parameter in determining quantity of residues to be harvested or grazed while allowing for soil productivity and erosion control. For instance, drylands yielding 60 bushels of corn and 35 bushels of wheat per acre cannot provide enough residues for grazing or harvest and for erosion control at the same time (Shanahan et al. 1998). Sometimes, the revised universal soil loss equation and the wind erosion equation are used to determine crop yield required at harvest to ensure that the amount of soil loss would not exceed the tolerable soil loss limit usually known as T (Nelson 2002). Using this procedure, Nelson found that three-year (1995-1997) annual average amounts of 2,523,872.8 tons of corn residues and 1,732,069.5 tons of wheat residues in Ohio could be removed from the field after harvest. However, the T values currently used for the tolerable soil loss by erosion may not necessarily provide an adequate level of protection. At T, over a billion tons of soil per year will continue to be lost in the US, jeopardizing wildlife habitat and air and water quality (Mann et al. 2002, Al-Kaisi 2003).

Corn/Wheat residues (lbs/acre) = Y*W* SGR (1),

where,

Y = Corn/Wheat yield (bushels/acre)

W = Weight (56 lbs for corn and 60 lbs for wheat per bushel)

SGR = straw-to-grain ratio (1.0 for corn, 1.3 for spring wheat and 1.7 for winter wheat)

The total amount of residues generated is estimated by multiplying the total number of acre harvested by the results of equation 1. For wheat, a SGR of 1.7 is used since Ohio production data are given only for winter wheat.

Data on acreage planted and harvested, crop yield and production for each crop were taken from the USDA website for each county in Ohio from 1997 to 2003. Instead of using production data for a single year, a seven-year annual average is used to estimate gross residues to account for annual variations. Even though research conducted from the central and northern Corn Belt indicated that removing residue in total or simply moving it away from the planted row could increase grain yield, several adjustments are necessary before residues left on the field after harvesting can be used for energy purposes. Hitzhusen et al. (1982) identified five adjustments including residues necessary for erosion control, harvesting efficiency (62.5%), moisture content (15%), storage and transportation loss (15%), and livestock uses including feeding and bedding. In this study, the following adjustments are made in order to estimate the amount of usable crop residues.

Combining beef and dairy cattle, Ohio has more than a million head of animals each year. For many reasons such as feed costs, cattlemen have become interested in using crop residues. Because of their multi-compartment ruminant stomach, cattle have the ability to digest fibrous materials such as grass and corn stalks. Residues can be used not only for feeding but also for bedding and energy. This entails taking into consideration these competing uses in estimating usable crop residues. Samples and McCuctheon (2002) and Myers (1992) indicate that from the total crop residues left on the field after harvest, animals would not consume more than 20 to 25 percent. Accounting for another arbitrary 5 percent for bedding, the gross residue amount for each county is multiplied by 70 percent.

A second adjustment aims at controlling for water and wind erosion through conservation tillage as recommended by the USDA. Conservation tillage is defined as any cropping system that maintains a minimum of 30 percent crop residue cover at all times to control for wind and water erosion. Variants of conservation tillage includes no-till, strip-till and ridge-till systems. Wind erosion typically removes fine particles and organic matter leaving the soil less productive. Crop residues reduce wind speeds at the soils surface, and standing stubble anchors the soil. Water erosion can remove the top layer of soil, which is the most fertile part. Or it can cut rills and gullies making those areas not only less productive but also in need of physical reclamation. This kind of erosion occurs on sloped land during snowmelt and rainfall events. Surface residues not only cushion the impact of raindrops so that soil particles are not easily detached; but also they slow the water flow allowing more infiltration and thereby reducing runoff and erosion.

The amount of residues required for erosion control varies with a number of factors such as soil structure and slope, climate, tillage practices and the number of operations performed. Depending on whether no-tillage or conventional tillage is performed and depending on the number of operations, more or less residues may be required for erosion control. No-till leaves the greatest amount of residues on the ground and erosion is contained at about 90 percent; whereas, as little as 5-10 percent of residue is left on the ground by moldboard plow. By the same token, many passes or operations bury all residues. To provide effective erosion control, soil conservation and management specialist R. Kline (2000) suggests 30% to 50% of soil surface residue cover which is equivalent to about 800 lbs of wheat residues and 1500 lbs of corn residues per acre. These figures along with the acreage planted (greater than acreage harvested) are used to estimate the amount of crop residues needed for erosion control in each county. Research shows that the residue surface cover allows controlling for soil organic matter (SOM) and thereby soil physical and chemical properties such as soil structure, pH, nutrient availability and cycling, ion exchange capacity, and buffering capacity (Tisdall et al. 1986, Maskina et al. 1993, and Follett 2001).

In the past, farmers used tillage mostly for weed control and land preparation for seeding. With the new effective herbicides and new equipment for seeding, tillage is not extensively needed. In addition, conservation tillage is advantageous environmentally as well as economically. To boost yield of future crops by eliminating weed seed, insects and diseases hosted by crop residues, a producer could plow under or burn the excess residues. However, these two practices have serious negative environmental impacts. For example, plowing exposes soil carbon and nitrogen to oxidation. This results in a loss of soil nitrogen and organic carbon along with emissions of carbon dioxide (CO_2), nitrogen oxides (NOx) and nitrogen dioxide (NO_2). The magnitude of these losses and emissions vary with the level disturbance of the soil. Compared to conventional tillage, practicing some form of conservation tillage such as no-till implies more carbon sequestrated and a friendlier environment. Investigating carbon sequestration rates from 67 long-term studies, West and Post (2002) concluded that across all cropping systems, except wheat-fallow, changing from conventional tillage to no-tillage could result in sequestration of .57 ± 0.14 Mg of carbon ha^{-1} $year^{-1}$. In addition, plowing under significant amount of crop residues with high carbon-to-nitrogen ratio such as corn stover (30:1 up to 70:1) requires application of fertilizers to the soil to avoid soil nutrient deficiency, because micro-organisms decomposing the residues compete for the soil nutrients such as nitrogen. Under conservation tillage, a farmer planting 500 acres can save as much as 225 hours and 1,750 gallons of fuel just in one planting season [Conservation Technology Information Center (CTIC)]. In 1999, conservation tillage was practiced on about 50 percent of Ohio's nearly 10 million acres of cropland. Besides, according to EPA, in 2000, conservation tillage was being used on about 60 percent of Ohio croplands. This tendency indicates that more Ohio farmers will practice conservation tillage in the future enlarging the potential for crop residues as a biomass energy resource while maintaining soil productivity. To deal with excess crop residues after accounting for erosion control and competing uses, crop producers would be able to give them away or sell them very cheaply to ethanol producers.

Allowing for erosion control yields the quantity of removable or harvestable crop residues. To account for efficiency or collectibility, this amount is multiplied by 62.5 percent. Still, two other adjustments are made after discounting for collectibility and competing uses. First, losses due to storage and transportation are assumed to be 15 percent. Second, an additional 15 percent to account for the moisture content of the residues is subtracted to report usable residues in dry weight basis. Ultimately, usable crop residues are converted into British Thermal Units (Btu) equivalents by multiplying times an average heat values factor of 7000 Btu's per pound of wheat straw and 8000 Btu's per pound of corn stover. One Btu is the amount of heat required to raise the temperature of one pound of water from 60 to 61 degrees Fahrenheit at normal atmospheric pressure which is 14.7 pounds per square inch.

The results of this process are presented in Figures 3.1 and 3.2, Map 3.1 and Table 3.3. Figure 3.1 indicates that an annual amount of 3,458,102 tons of usable crop residues is produced in Ohio. Of this amount corn stover accounts for 74.08% and wheat straw represents 25.92%. From Figure 3.2, it can be seen that the greatest amount of crop residues is produced in the northwestern and western regions and the smallest amount in the southeastern, eastern and northeastern regions. This is so because these regions are highly forested as will be seen later in the next section on forest residues. Likewise, counties producing the greatest amount of crop residues can be seen by looking at Map 3.1. For example, Darke, Putnam, Henry and Wood are the counties which produce the greatest amount of crop residues. Map 3.1 also points out a number of counties for which the amount of usable crop residues is actually negative. As a result, removing crop residues from the field may lead to erosion problem. Table 3.3 indicates that the amount of usable crop residues varies from several counties with negative values to a high value of 128,723 dry tons or 2 trillions BTU's per year in Wood County.

Table 3.2: Crop Residues to Product Ratios Used in the Literature

Authors	RPR	Moisture content (%)	Carbon (%)	Nitrogen	Ash
Corn					
Metzger and Benford (2001).	1.5		40		
Koopsman and Koppejan (1997)	2.00	15			
Bhattacharya et al. (1993)					
Ryan and Openshaw (1991)	1.00-2.50	Air dry			
Hitzhusen et al. (1982)	1.5	15			
Average	1.68	15			
Soybean					
Metzger and Benford (2001).	1.5		40		
Koopsman and Koppejan (1997)	3.5	15			
Bhattacharya et al. (1993)	3.5	15	42.55		12.38
Average	2.83	15			
Wheat					
Metzger and Benford (2001).	1.5		40.00		
Koopsman and Koppejan (1997)	1.75	15			
Bhattacharya et al. (1993)	1.75	15	42.5		12.38
Ryan and Openshaw (1991)	0.70-1.80				
Hitzhusen et al. (1982)	1.70	15			
Average	1.53	15			

Figure 3.1: Annual Usable Crop Residues in Ohio

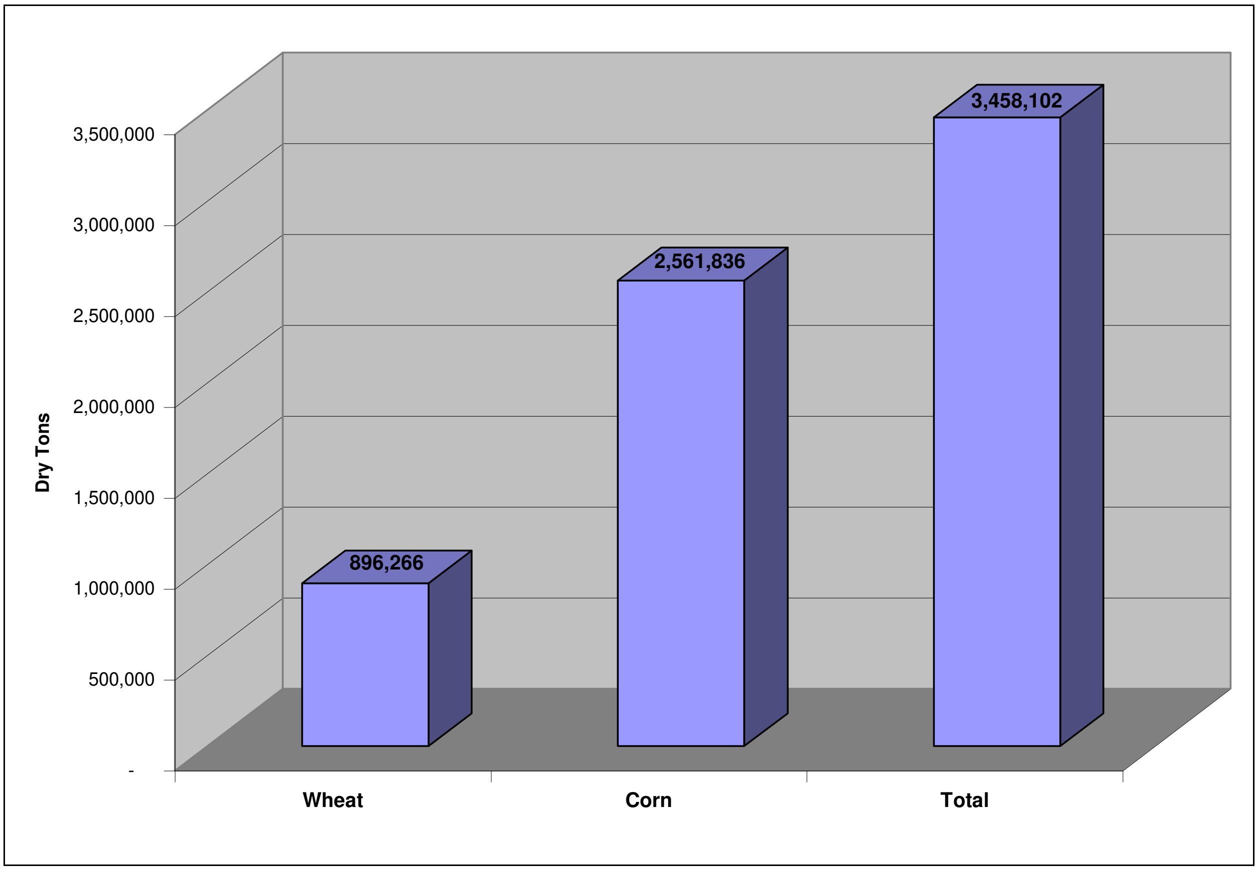
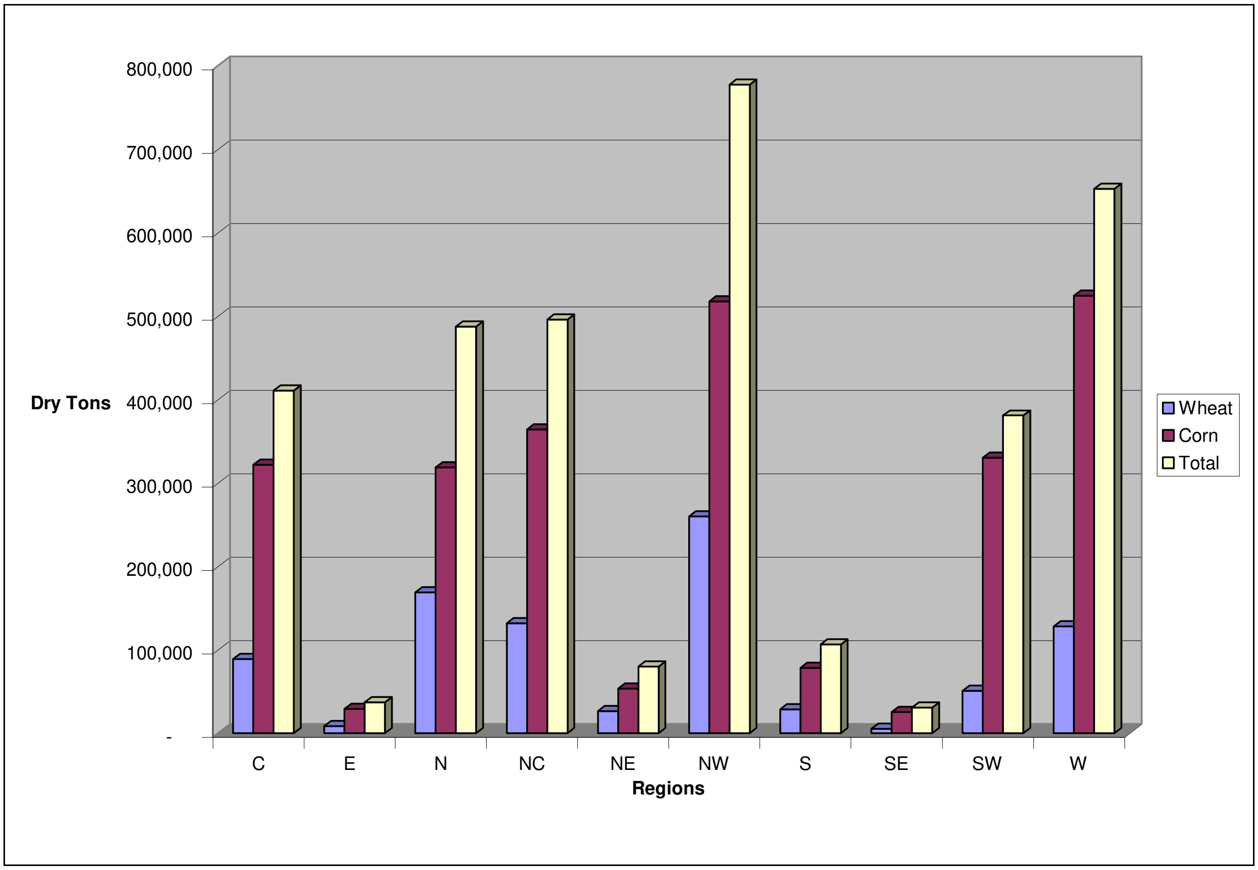


Figure 3.2: Usable Crop Residues Distribution among Geographical Units



Map 3.1: Distribution of Usable Crop Residues among Ohio Counties

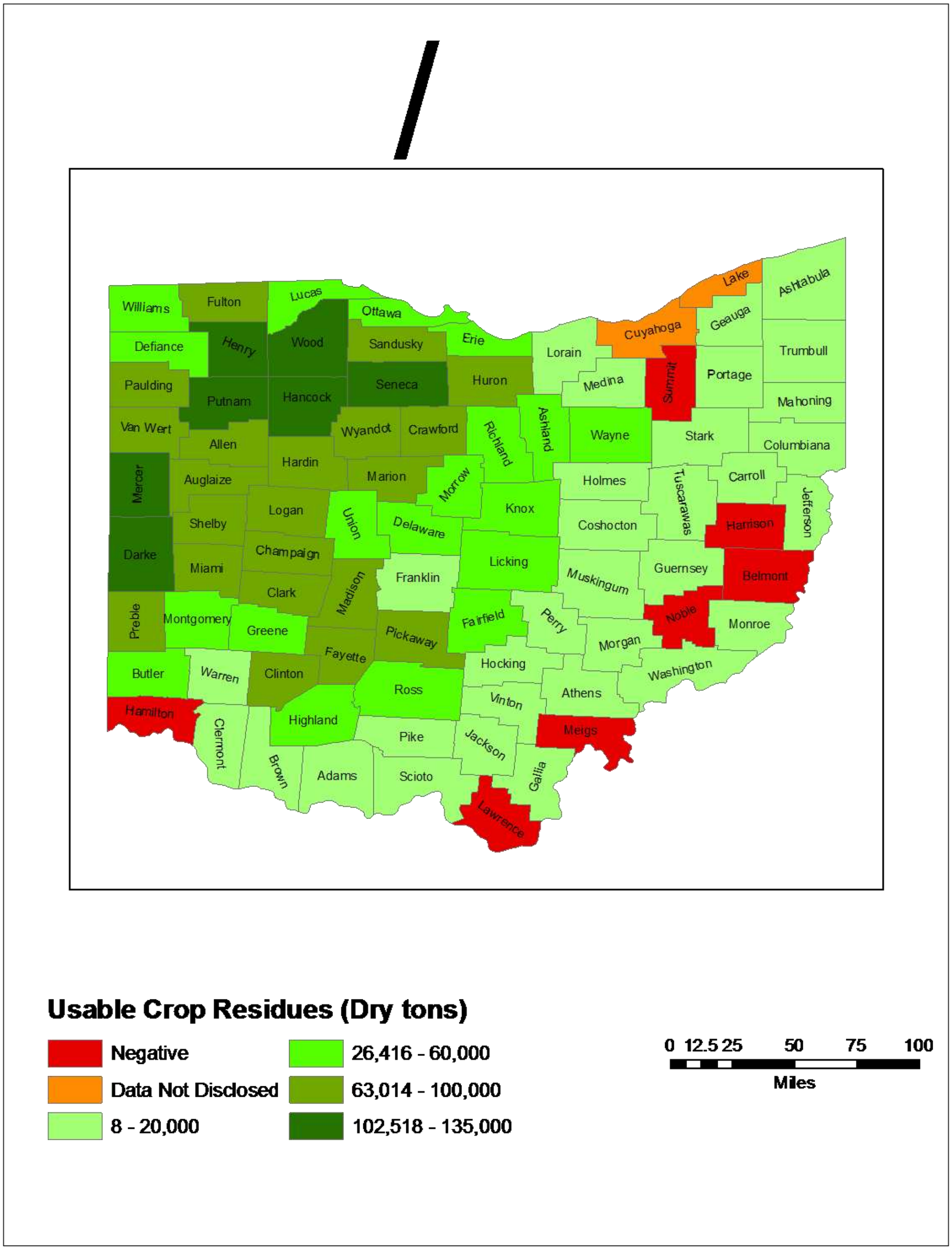


Table 3.3: Estimates of Annual Average Usable Crops Residues in Ohio by County and Geographic Unit (1997-2003)

Regions	Counties	Wheat Residues (Dry tons)			Corn Residues (Dry Tons)			Total		
		Gross	Usable	Btu	Gross	Usable	Btu	Usable	Btu	Rank
Central	Delaware	43,267	11,277	157.9	144,955	32,098	513.6	43,375	671.4	39
	Fairfield	43,558	11,312	158.4	216,155	46,950	751.2	58,262	909.6	29
	Franklin	22,015	5,787	81.0	75,087	12,563	201.0	18,351	282.0	53
	Licking	28,293	7,250	101.5	178,214	39,592	633.5	46,843	735.0	34
	Madison	44,532	11,793	165.1	335,549	76,973	1,231.6	88,766	1,396.7	9
	Pickaway	92,083	24,227	339.2	313,180	71,276	1,140.4	95,504	1,479.6	16
	Union	66,548	17,328	242.6	180,812	42,257	676.1	59,585	918.7	36
	Total Central	**340,296**	**88,974**	**1,246**	**1,443,953**	**321,711**	**5,147**	**410,685**	**6,393**	**5**
Eastern	Belmont	-	-	-	3,778	(417)	(6.7)	(417)	(6.7)	81
	Carroll	6,124	1,512	21.2	21,832	(37)	(0.6)	1,476	20.6	72
	Coshocton	8,648	2,148	30.1	88,715	15,502	248.0	17,649	278.1	54
	Guernsey	-	-	-	10,598	1,584	25.3	1,584	25.3	71
	Harrison	-	-	-	7,250	(2,624)	(42.0)	(2,624)	(42.0)	86
	Holmes	10,454	2,667	37.3	63,546	8,789	140.6	11,456	178.0	59
	Jefferson	-	-	-	5,675	778	12.4	778	12.4	76
	Monroe	-	-	-	4,253	541	8.7	541	8.7	77
	Tuscarawas	7,874	1,864	26.1	47,962	4,696	75.1	6,560	101.2	66
	Total Eastern	**33,099**	**8,192**	**115**	**253,609**	**28,812**	**461**	**37,004**	**576**	**9**
Northern	Erie	27,214	7,129	99.8	103,541	21,282	340.5	28,410	440.3	46
	Huron	86,609	22,675	317.5	219,084	50,581	809.3	73,256	1,126.7	18
	Lorain	31,745	8,014	112.2	74,432	11,926	190.8	19,940	303.0	52
	Lucas	29,946	7,933	111.1	96,795	22,710	363.4	30,643	474.4	44
	Ottawa	50,802	13,178	184.5	62,851	13,495	215.9	26,674	400.4	58
	Sandusky	74,580	19,665	275.3	230,894	51,633	826.1	71,298	1,101.4	25
	Seneca	144,135	37,427	524.0	285,011	65,091	1,041.5	102,518	1,565.4	24
	Wood	199,419	52,894	740.5	362,412	81,850	1,309.6	134,744	2,050.1	5
	Total Northern	**644,450**	**168,916**	**2,365**	**1,435,020**	**318,568**	**5,097.1**	**487,483**	**7,461.9**	**4**
North Central	Ashland	25,868	6,515	91.2	108,994	21,230	339.7	27,745	430.9	47
	Crawford	101,605	26,680	373.5	284,267	62,113	993.8	88,793	1,367.3	11
	Hardin	84,927	22,084	309.2	267,328	61,868	989.9	83,952	1,299.1	12
	Knox	18,756	4,719	66.1	153,098	32,016	512.3	36,735	578.3	41
	Marion	69,927	18,334	256.7	225,113	52,781	844.5	71,115	1,101.2	20
	Morrow	42,373	11,043	154.6	147,817	33,743	539.9	44,786	694.5	38
	Richland	30,317	7,748	108.5	101,670	19,311	309.0	27,060	417.5	28
	Wayne	35,358	9,179	128.5	177,733	31,535	504.6	40,714	633.1	42
	Wyandot	98,017	25,391	355.5	226,479	49,420	790.7	74,811	1,146.2	6
	Total North central	**507,148**	**131,693**	**1,844**	**1,692,498**	**364,017**	**5,824**	**495,709**	**7,668**	**3**

Regions	Counties	Wheat Residues (Dry tons)			Corn Residues (Dry Tons)			Total		
		Gross	Usable	Btu	Gross	Usable	Btu	Usable	Btu	Rank
North Eastern	Ashtabula	13,441	3,330	46.6	44,133	7,148	114.4	10,478	161.0	61
	Columbiana	17,162	4,313	60.4	58,119	9,725	155.6	14,038	216.0	57
	Cuyahoga	-	-	-		-	-	-	-	NA
	Geauga	4,167	1,046	14.6	10,573	(988)	(15.8)	58	(1.2)	80
	Lake	-	-	-		-	-	-	-	NA
	Mahoning	9,962	2,514	35.2	38,649	6,590	105.4	9,104	140.6	63
	Medina	18,233	4,592	64.3	43,555	3,491	55.9	8,083	120.1	65
	Portage	10,727	2,658	37.2	38,266	3,401	54.4	6,059	91.6	70
	Stark	19,486	4,859	68.0	79,533	14,641	234.3	19,500	302.3	45
	Summit	-	-	-	4,907	(60)	(1.0)	(60)	-	69
	Trumbull	12,555	3,166	44.3	55,873	9,460	151.4	12,626	195.7	62
	Total Northeastern	**105,735**	**26,478**	**371**	**373,608**	**53,409**	**855**	**79,887**	**1,225**	**8**
North Western	Allen	76,462	20,214	283.0	219,951	48,871	781.9	69,084	1,064.9	21
	Defiance	79,614	20,397	285.6	166,787	37,567	601.1	57,964	886.6	31
	Fulton	66,285	17,665	247.3	323,545	77,291	1,236.7	94,956	1,484.0	7
	Hancock	146,755	38,616	540.6	307,234	68,812	1,101.0	107,428	1,641.6	3
	Henry	145,737	38,731	542.2	304,507	72,275	1,156.4	111,005	1,698.6	2
	Paulding	141,971	36,699	513.8	195,873	42,097	673.6	78,796	1,187.3	32
	Putnam	178,072	46,828	655.6	281,511	64,580	1,033.3	111,408	1,688.9	17
	Van Wert	85,899	22,866	320.1	299,537	70,413	1,126.6	93,280	1,446.7	10
	Williams	68,624	17,708	247.9	168,249	35,833	573.3	53,540	821.2	37
	Total Northwestern	**989,420**	**259,723**	**3,636**	**2,267,195**	**517,739**	**8,284**	**777,463**	**11,920**	**1**
Southern	Adams	8,046	1,841	25.8	35,891	6,618	105.9	8,459	131.7	64
	Gallia	-	-	-	8,047	1,136	18.2	1,136	18.2	73
	Highland	36,256	9,138	127.9	134,014	29,995	479.9	39,133	607.8	40
	Jackson	2,387	547	7.7	10,072	(329)	(5.3)	218	2.4	78
	Lawrence	-	-	-	3,317	(2,227)	(35.6)	(2,227)	(35.6)	85
	Pike	2,598	626	8.8	18,125	228	3.7	854	12.4	49
	Ross	58,333	15,038	210.5	176,223	40,405	646.5	55,443	857.0	33
	Scioto	4,412	1,081	15.1	25,160	2,191	35.1	3,272	50.2	51
	Total Southern	**112,031**	**28,271**	**396**	**410,850**	**78,016**	**1,248**	**106,288**	**1,644**	**7**
South East	Athens	-	-	-	6,152	943	15.1	943	15.1	74
	Hocking	-	-	-	8,259	8	0.1	8	0.1	79
	Meigs	2,321	553	7.7	8,447	(1,568)	(25.1)	(1,015)	(17.4)	83
	Morgan	-	-	-	8,812	899	14.4	899	14.4	75
	Muskingum	7,276	1,719	24.1	49,146	9,507	152.1	11,226	176.2	60
	Noble	-	-	-	3,054	(2,058)	(32.9)	(2,058)	(32.9)	84
	Perry	7,529	1,802	25.2	63,359	13,776	220.4	15,578	245.6	35
	Vinton	-	-	-	3,530	168	2.7	168	2.7	50
	Washington	4,862	1,121	15.7	30,150	3,695	59.1	4,817	74.8	67
	Total Southeast	**21,988**	**5,195**	**72.7**	**180,910**	**25,369**	**406**	**30,564**	**478.6**	**10**

Regions	Counties	Wheat Residues (Dry tons)			Corn Residues (Dry Tons)			Total		
		Gross	Usable	Btu	Gross	Usable	Btu	Usable	Btu	Rank
South West	Brown	-	2,160	30.2	77,472	15,146	242.3	17,306	272.6	55
	Butler	21,951	5,473	76.6	98,367	20,943	335.1	26,416	411.7	48
	Clermont	5,239	1,215	17.0	38,208	5,231	83.7	6,447	100.7	68
	Clinton	27,520	6,934	97.1	274,308	64,326	1,029.2	71,260	1,126.3	19
	Fayette	46,135	12,196	170.7	300,202	69,506	1,112.1	81,702	1,282.8	13
	Greene	24,099	6,170	86.4	216,738	50,613	809.8	56,783	896.2	30
	Hamilton	-	-	-	14,571	(920)	(14.7)	(920)	(14.7)	82
	Montgomery	17,920	4,552	63.7	122,457	26,434	422.9	30,986	486.7	43
	Preble	31,642	8,113	113.6	277,274	63,773	1,020.4	71,886	1,134.0	23
	Warren	15,373	3,830	53.6	82,543	14,968	239.5	18,798	293.1	56
	Total South West	**189,878**	**50,642**	**709.0**	**1,502,140**	**330,020**	**5,280.3**	**380,663**	**5,989.3**	**6**
West	Auglaize	88,810	23,464	328.5	215,779	45,956	735.3	69,419	1,063.8	22
	Champaign	30,115	7,901	110.6	302,477	68,445	1,095.1	76,346	1,205.7	14
	Clark	24,251	6,329	88.6	240,171	56,815	909.0	63,144	997.6	26
	Darke	93,468	24,714	346.0	451,048	104,009	1,664.1	128,723	2,010.1	1
	Logan	47,531	12,444	174.2	224,012	50,571	809.1	63,014	983.3	27
	Mercer	98,642	26,277	367.9	331,683	76,477	1,223.6	102,754	1,591.5	4
	Miami	39,194	10,333	144.7	280,070	65,862	1,053.8	76,194	1,198.4	15
	Shelby	63,549	16,720	234.1	241,918	56,042	896.7	72,762	1,130.8	8
	Total West	**485,559**	**128,182**	**1,794.5**	**2,287,158**	**524,175**	**8,386.8**	**652,357**	**10,181.3**	**2**
Ohio	**Total**	**3,438,377**	**896,266**	**12,548**	**11,846,941**	**2,561,836**	**40,989**	**3,458,102**	**53,537**	-

4- Wood residues

Wood biomass is a substantial renewable resource that can be used as a fuel to generate electric power and other forms of energy products. For example, new technologies have been developed to convert wood biomass into ethanol. Burning wood produces 90% less sulfur than coal. Wood residues come from a wide variety of sources. Walsh et al. (2000) use MSW and C&D wastes to estimate urban wood residues. Wiltsee (1998) utilizes three sources of urban wood to estimate wood residues: MSW, C&D, and industrial wood wastes. The annual wood inventory by McKeever (1995, 1996, 1998, 1999 and 2003) considers three main sources of wood wastes as well: MSW, C&D, and primary timber processing. In some states such as Florida, C&D is part of MSW. In Ohio, however, C&D and other non-MSW are not included in MSW.

According to McKeever, two categories of MSW are good sources for wood recovery, wood and yard trimmings. However, since 1990, much of the yard wastes generated in Ohio has been composted or managed by direct land application and has not been a part of the waste generation totals. In addition, the 2000 State of Garbage in America reports that among the states Ohio has the largest number of yard trimmings composting sites, implying that yard trimmings are not generally available for energy purposes.

In this study, four main sources of wood residues are considered:

1) Forest residues
2) Primary and secondary wood manufacturers
3) Municipal solid waste (MSW)
4) Construction and demolition debris (C&D).

For each source of wood, the Btu equivalent is estimated**.** In burning wood for energy, it is important that the moisture be as low as possible to recover as much heat value as possible. Water contained in wood vaporized during combustion, and each pound of water vaporized uses 1200 Btu, resulting in a loss of energy. With no moisture content (bone dry), wood of any species has a heat value of 8600 Btu per pound. However, this moisture content can be only achieved by baking wood in an oven before burning it. As a result, wood is burned more often than not at a 20 percent moisture content (air-dry wood) where the heat value is 6400 Btu's per pound[3]. This energy conversion factor is used in this study to calculate the Btu equivalent of wood residues, because moisture content of MSW and C&D wood is about 10%-30%[4]. For forest residues, data amount is reported on a dry ton basis using a conversion rate of 14 dry tons

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[3] Source: http://bioenergy.ornl.gov/papers/misc/energy_conv.html
[4] Source: http://engr.uga.edu/service/outreach/publications/wood/webtransfer/wood_home_page.htm

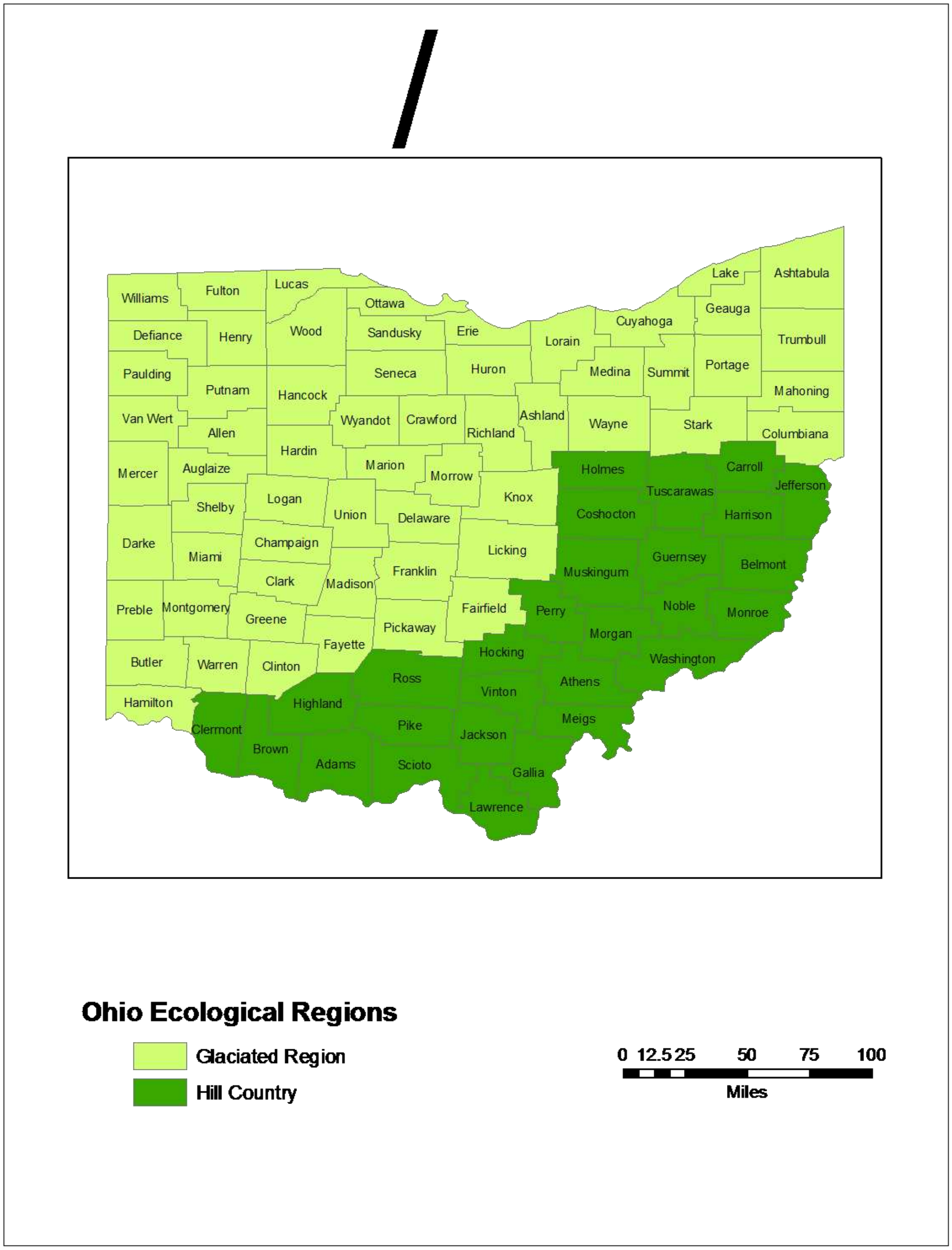
for 1000 cubit feet based according to the Nation Renewable Energy Laboratory (NREL). To convert forest and mill residues in energy, the assumption of air-dryness was necessary.

4.1- Forest residues

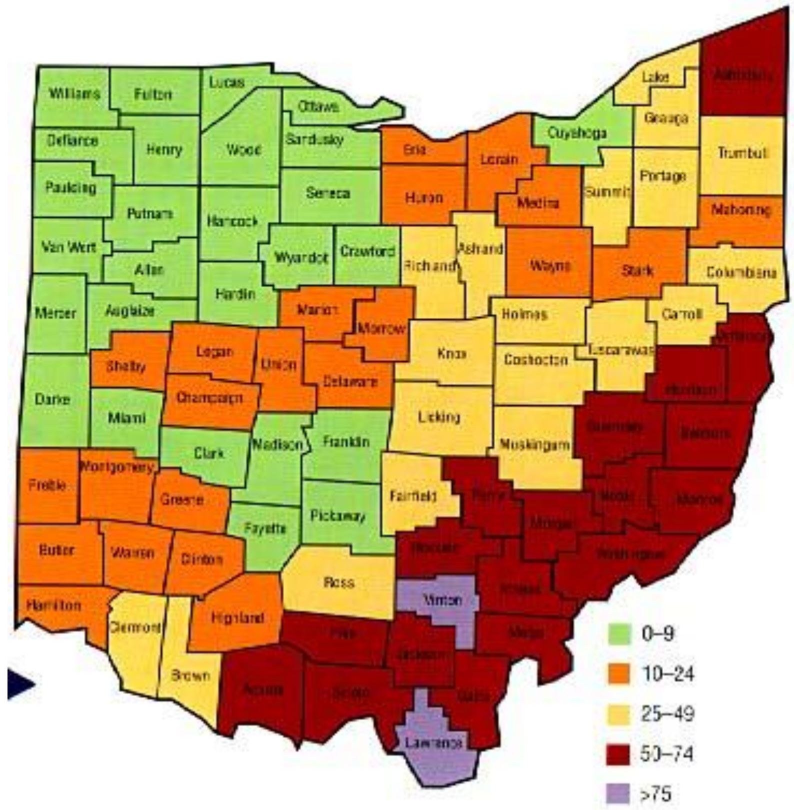
Forest residues include logging residues, rough rotten salvageable dead wood, and excess small pole trees and material resulting from forest management operations i.e. sawdust, offcuts etc. Previous studies have shown that Ohio has a considerable area covered by forests, which can generate significant amount of residues. Ohio harvests 300-400 million board feet of timber each year (US Forest Service Facts and Figures). As of today, Ohio's forests cover 7.9 million acres, representing over 30 percent of the state (OSU extension). Due to costly collection and transportation of forest residues, wood wastes from wood processing manufacturers are mostly used as a biomass resource for heat.

According to Ervin et al. (1994), Ohio is divided into two general ecological regions: the Hill country and the Glaciated Region (See Map 4.1). "Sixty-three percent of the forest land is found in the Hill Country on one third of the land base. Conversely, the remaining 37 percent are found in the Glaciated Region. Within the Hill Country most counties are at least 50 percent forested, with two counties (Lawrence and Vinton) more than 75 percent forested. The most forested part of the Glaciated Region is in the extreme northeast corner of the state. Otherwise, most of the counties are less than 25 percent forested with many less than 10 percent" (See Map 4.2). As a result, the amount of forest residues is expected to be larger for those counties located in the Hill Country region.

Map 4.1: Ohio Ecological Regions



Map 4.2: Forest Distribution across the Counties in Ohio



Three methods could be used to estimate forest wood residues:

1. The first method is to use the annual average amount of forest wood harvested in each county and apply some forest residue generation rates. A study by Southgate and Shakya (1996) develops a linear programming model to identify potential sites for biomass power plants in Ohio. They divided Ohio into 50 regions and provided forest residues and wood waste data for each region. Each region is either a stand-alone county or a group of counties. While the wood waste data are from a survey of wood manufacturers completed by Shakya (1995), forest residues are estimated from the 1991 forest statistics for Ohio using the general rule that for every 1000 board feet of saw timber harvested, two tons of forest residues are generated. Another paper by Koopsman and Koppejan (1997)

utililizes the residue to product ratio (RPR) method to estimate forest and wood processing residues. Table 4.1 reports the residue generation rates used by the above referenced authors.

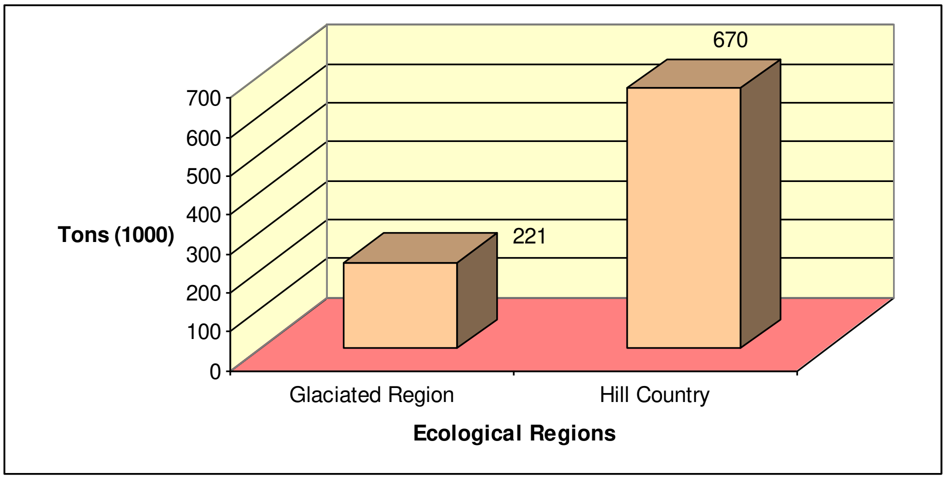
2. The second method is to use the Ohio annual average growth rate of forest wood harvested to update the 1996 Southgate and Shakya estimates.
3. The third method would be to collect forest wood residues data from the USDA or the Ohio Division of Forestry (ODF) of the Ohio Department of Natural Resources, as done by Block and Ebadian (2003) in a previous study for which data such as acreage of forestland, type of forest, and mass of waste generated per year were collected from Florida Department of Forestry and the United States Department of Agriculture (USDA).

The problem with the first method is that it does not account for other forest removals which are unused forest debris. Lack of data makes the second approach unrealistic. The problem with the third approach is that it is not known whether ODF collects and maintains forest and urban wood waste data. Attempts to contact ODF were unsuccessful. Still, the feasible method remains the third one. Data on forest residues were collected from the Forest Inventory and Analysis (FIA) unit of the USDA. Logging residues and other removals data provided by FIA are used to estimate forest residues. Data collected are converted in dry tons using a rate of 1000 cubic feet for 14 dry tons as prescribed by National Renewable Energy Laboratory (NREL). Forest residues are then converted into Btu equivalents assuming a rate of 6450 Btu's per pound of residues as stated earlier. The results are presented in Figure 4.1, Map 4.3 and Table 4.2. Figure 4.1 shows that the largest amount of forest residues is found in the Hill Country region as expected. As can be seen in Table 4.2, the amount of forest residues varies from counties with no forest residues at all to the high value of 1,211.5 dry tons in Ross County. Map 4.3 indicates the spatial location of these counties. This result is unexpected since Vinton and Lawrence are counties that are forested at more than 75%. Those counties were expected to produce the highest amount of forest residues. Finally, the table portrays an amount of 1,525,541 dry tons forest residues available in Ohio for the year 2002.

Table 4.1: Forest and Wood Residue Recovery Rate

<table>
<tr><td colspan="3">Shakya 1995</td></tr>
<tr><td colspan="3">1000 board feet saw timber harvested generate 2 tons of forest residues</td></tr>
<tr><td colspan="3">Koopsman and Koppejan 1997</td></tr>
<tr><td></td><td>Type of residue</td><td>Residue generation rate (%)</td></tr>
<tr><td>Forest residues</td><td>Logging</td><td>40</td></tr>
<tr><td rowspan="3">Wood processing residues</td><td>Saw-milling</td><td>50</td></tr>
<tr><td>Plywood production</td><td>50</td></tr>
<tr><td>Particle board</td><td>10</td></tr>
</table>

Figure 4.1: Distribution of Forest Residues between the Two Ohio Ecological Regions



Map 4.3: Forest Residues Distribution among Ohio Counties.

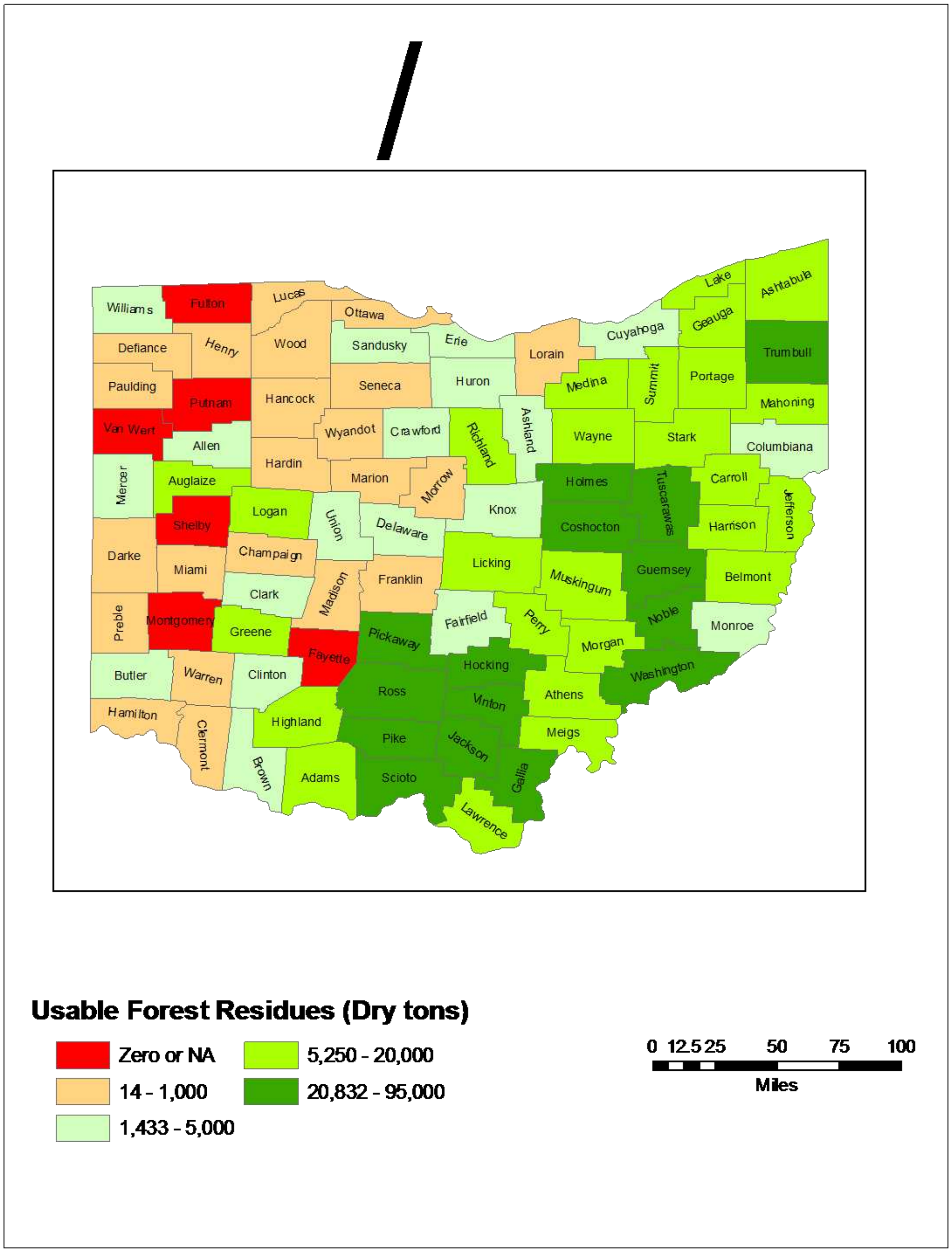

Williams
Fulton
Lucas
Ottawa
Lake
Ashtabula
Defiance
Henry
Wood
Sandusky
Erie
Lorain
Cuyahoga
Geauga
Trumbull
Paulding
Putnam
Hancock
Seneca
Huron
Medina
Summit
Portage
Mahoning
Van Wert
Allen
Wyandot
Crawford
Richland
Ashland
Wayne
Stark
Columbiana
Mercer
Auglaize
Hardin
Marion
Morrow
Holmes
Tuscarawas
Carroll
Jefferson
Shelby
Logan
Union
Delaware
Knox
Coshocton
Harrison
Darke
Miami
Champaign
Licking
Muskingum
Guernsey
Belmont
Clark
Madison
Franklin
Preble
Montgomery
Greene
Pickaway
Fairfield
Perry
Morgan
Noble
Monroe
Fayette
Hocking
Washington
Butler
Warren
Clinton
Ross
Vinton
Athens
Hamilton
Clermont
Highland
Pike
Jackson
Meigs
Brown
Adams
Scioto
Gallia
Lawrence
Usable Forest Residues (Dry tons)
Zero or NA
14 - 1,000
1,433 - 5,000
5,250 - 20,000
20,832 - 95,000
0 12.5 25 50 75 100
Miles

Table 4.2: Estimates of Forest Residues by Ohio County and Geographic Unit

Regions	Counties	Forest residues		
		Usable (dry Tons)	Btu (Billions)	Rank
Central	Delaware	1,433	18.3	60
	Fairfield	1,947	24.9	55
	Franklin	53	0.7	79
	Licking	9,077	116.2	29
	Madison	77	1.0	78
	Pickaway	20,832	266.6	15
	Union	3,370	43.1	45
	Total Central	**36,788**	**471**	**5**
East	Belmont	12,938	165.6	24
	Carroll	8,057	103.1	30
	Coshocton	48,629	622.4	3
	Guernsey	27,358	350.2	10
	Harrison	6,329	81.0	36
	Holmes	41,513	531.4	5
	Jefferson	6,765	86.6	34
	Monroe	2,013	25.8	53
	Tuscarawas	48,587	621.9	4
	Total Eastern	**202,188**	**2,588**	**2**
North	Erie	1,973	25.3	54
	Huron	1,444	18.5	59
	Lorain	429	5.5	71
	Lucas	601	7.7	68
	Ottawa	296	3.8	73
	Sandusky	4,050	51.8	43
	Seneca	783	10.0	66
	Wood	900	11.5	61
	Total Northern	**10,475**	**134**	**9**
North Central	Ashland	2,033	26.0	52
	Crawford	1,517	19.4	58
	Hardin	199	2.5	74
	Knox	3,126	40.0	46
	Marion	150	1.9	77
	Morrow	445	5.7	70
	Richland	5,250	67.2	41
	Wayne	18,045	231.0	16
	Wyandot	153	2.0	76
	Total Northcentral	**30,918**	**396**	**6**

Regions	Counties	Forest Residues		
		Usable (dry Tons)	Btu (Billions)	Rank
North East	Ashtabula	12,956	165.8	23
	Columbiana	1,627	20.8	57
	Cuyahoga	2,336	29.9	49
	Geauga	17,840	228.4	18
	Lake	6,557	83.9	35
	Mahoning	7,817	100.1	31
	Medina	14,167	181.3	21
	Portage	6,203	79.4	37
	Stark	9,737	124.6	27
	Summit	7,379	94.5	32
	Trumbull	20,928	267.9	14
	Total Northeastern	**107,549**	**1,377**	**4**
North West	Allen	2,266	29.0	51
	Defiance	889	11.4	62
	Fulton	0	-	84
	Hancock	810	10.4	65
	Henry	470	6.0	69
	Paulding	16	0.2	81
	Putnam	0	-	86
	Van Wert	0	-	88
	Williams	2,405	30.8	48
	Total Northwestern	**6,857**	**88**	**10**
South	Adams	11,090	142.0	25
	Gallia	23,933	306.3	12
	Highland	6,124	78.4	38
	Jackson	28,138	360.2	8
	Lawrence	5,376	68.8	40
	Pike	26,524	339.5	11
	Ross	94,650	1,211.5	1
	Scioto	59,974	767.7	2
	Total Southern	**255,809**	**3,274**	**1**
South East	Athens	15,734	201.4	20
	Hocking	39,469	505.2	6
	Meigs	17,763	227.4	19
	Morgan	10,611	135.8	26
	Muskingum	13,910	178.1	22
	Noble	22,438	287.2	13
	Perry	17,877	228.8	17
	Vinton	34,966	447.6	7
	Washington	28,052	359.1	9
	Total Southeastern	**200,821**	**2,571**	**3**

Regions	Counties	Forest Residues		
		Usable (dry Tons)	Btu (Billions)	Rank
Southwestern	Brown	2,317	29.7	50
	Butler	4,975	63.7	42
	Clermont	50	0.6	80
	Clinton	1,638	21.0	56
	Fayette	0	-	83
	Greene	9,123	116.8	28
	Hamilton	620	7.9	67
	Montgomery	0	-	85
	Preble	825	10.6	64
	Warren	396	5.1	72
	Total Southwestern	**19,943**	**255.3**	**7**
Western	Auglaize	5,531	70.8	39
	Champaign	14	0.2	82
	Clark	3,557	45.5	44
	Darke	868	11.1	63
	Logan	6,878	88.0	33
	Mercer	2,645	33.9	47
	Miami	167	2.1	75
	Shelby	0	-	87
	Total West	**19,661**	**251.7**	**8**
Ohio	**Total**	**1,525,541**	**11,404.9**	-

4.2- Wood wastes from primary and secondary wood manufacturers.

Primary and secondary wood manufacturers generate a significant amount of wood wastes including, but not limited to, chips, sawmill slabs and edgings, bark, sawdust, peeler log cores, trimmings, and ply-residues. In 1996, USDA (1997) found that the wood product industries in Ohio were composed of 1720 secondary and primary-manufacturing firms. This number has grown to approximately 2000 (US Forest Service Facts and Figures). The classification of wood product manufacturers as primary and secondary is based upon raw material usage and their finished products. A primary manufacturer uses round wood (logs) to produce commodity lumber and panel products. These companies include logging contractors, sawmills, pulpmills, and veneer plants. Each of these companies transforms round wood into a type of final product. Logging contractors process timber into logs. In turn, sawmills transform logs into rough, green and dried lumber. While fiber is derived from pulpwood by pulpmills, veneer and plywood are made from peeling high quality of logs by veneer plants.

A secondary manufacturer takes primary wood products and physically alters them by changing the dimension, shape, chemical composition, or appearance. These companies include cabinet, millwork, furniture, pallet and paper manufacturers.

According to Shakya (1997), in Ohio, the larger amount of wood processing residues is generated by the secondary wood manufacturers (See Table 4.3). Also, processing wood wastes generated in Ohio are used in a number of ways. Four general categories of use are listed: given away, sell, internal uses, and land fill. In the primary sector, the percentages of wood waste given away and land filled are respectively 15.1% and 1.9%. However, the secondary sector on average gives away 31.5% and land fills 18.9% of the wood residues generated. Only wood residues given away and land filled would be considered as potential residues for energy purposes. If part of the landfilled wood residues is recovered for recycling; only the remaining portion can be converted to energy.

Table 4.3: Average Amount of Wood Residues Generated and Used in Ohio by Sector in 1997 (Tons)

Sector		Wood Waste Generated		General Trend of Uses and Disposal (%)			
		Quantity*	Percentage (%)	Given away	Sell	Internal uses	Land filled
Primary		9195	9.3	15.1	67.9	15.1	1.9
Secondary	Large	88630	90.1	12.8	44.7	17.0	25.5
	Small	555	0.6	25.0	23.2	14.3	37.5
Total		98380	100.0	-	-	-	-

Source: Shakya 1997, survey results
***: Not included wood wastes from the Construction & Demolition sector**

A study by the North Carolina Department of Environment and Natural Resources (NCDENR) attempts to estimate wood wastes from primary and secondary wood manufacturers in North Carolina. In the NCDENR study, while the annual national wood inventory study by McKeever was used to estimate primary wood residues, MSW from two other studies was used to estimate secondary wood processing wastes. Based on the McKeever's national estimates, the NCDENR develops a per capita generation figure and applies it to North Carolina population to estimate wood residues from primary wood manufactures. The methodology applied in NCDENR is applicable to this current study. As shown in Shakya (1997), wood residues from secondary wood manufacturers would be best captured from municipal solid waste. Also, the inventory of wood residuals by McKeever (2003) reports that about 98% of the wood residues from the primary wood manufacturers was recovered for recycling. However, national estimates may not reflect local conditions.

The best way to gather data on wood residues from primary and secondary wood manufacturers would be personal interviews through a questionnaire. Time and budget constraints make this method unfeasible. A more feasible approach given resource constraints would entail applying the residue generation rates to the total amount of wood used by the primary wood manufacturers in each county in Ohio. However, the amount of wood used by the primary wood manufactures is not available for all counties in Ohio, making this method also impracticable. Therefore, resorting to data on mill residues in dry tons provided by FIA for the year 1997 is the best alternative for wood residues from primary wood manufacturers. As Patrick Miles[5] indicates, the 1997 data is the best proxy for 2002 since no data were collected for 2002. As done for forest residues, mill residues are converted into Btu equivalent. As will be seen in section 4.4, to estimate wood residues from secondary wood manufacturers, municipal solid waste data for each county in Ohio are used.

Table 4.8 presents the gross and the usable amount of mill residues per county, geographical unit and for Ohio. As shown in the table, a gross amount of 942,943 dry tons mill residues is generated in Ohio. From this amount only 2.3% is available for use. The reason is that most of the mill residues are being used either as fuel or as raw fiber material to produce products such as pulp and paper. Also, most of the mill facilities have on-site power plants to alleviate their internal energy costs, making mill residues less likely to be landfilled. Among the regions, the northeastern produced the largest amount of mills residues. At the county level, Belmont and Mahoning generate the largest amounts of usable mill residues which are respectively 2,402 and 2,188 dry tons.

[5] Personal communication with Patrick Miles from Forest Inventory Analysis unit of the USDA

4.3- Construction and demolition debris

Construction and demolition is generally referred to as a single waste type. However, as McKeever (1999) argues, they should be separated as they differ in origin and characteristics. Whereas wood is typically the largest component of waste material generated at construction and renovation sites, concrete is commonly the largest component of building demolition debris. Wood residues generated from C&D consist of forming and framing lumber, stumps, plywood, laminates, and scraps. Wastes from C&D debris such as road and bridge construction and demolition, and land clearing debris are not included in this study.

C&D wood residues are attractive as a fuel because of low moisture content. As a result, they contain a high Btu value. However, wood wastes produced at construction sites generally have a better potential for reuse than wood from demolition sites due to the ease of separating the materials. New construction waste can be more readily separated on the construction site through some additional effort by the builder. Demolition wood is often not only less efficient and less desirable, but also more costly because of contamination with other materials such as paints, nails, fasteners, wall covering materials, and insulation. Compared to demolition, new construction usually tends to generate much cleaner wood wastes that are more uniformly derived from fresh wood products. Therefore, most new construction wood waste is clean, unpainted, untreated and recyclable. Consequently, recycling rate of new construction wood waste is expected to be higher. These differences entail evaluating new construction waste and demolition waste separately. McKeever (2003) estimates the total of wood waste from C&D using per capita C&D waste generation rates, population estimates, construction waste estimates, demolition debris disposal rates and composition, and average recovery rate.

There are two major categories of C&D debris: residential and non-residential. Each category is further broken down into three subcategories: construction, renovation and demolition. Renovation includes improvements and repairs. Also, residential structures encompass single-family and multi-family units. To estimate wood waste from construction and demolition debris for both residential and non-residential, two approaches can be used. The first approach is to derive wood waste directly by applying wood waste generation rates per square foot of floor area to total square footage of new residential and non-residential units built in each county. This approach rests upon two studies: Yost and Lund (1997) from the National Association of Home Builders Research Center and Gordon at al. (2003). Yost and Lund suggest using wood waste generation rates varying between 1.3 and 2.1 lbs/square foot. Gordon, on the other hand, reports on a pilot project of 13 building sites in Colorado which tests separation and recovery of wood waste during new construction of residential and commercial structures. This experiment yields 7.2 cubic yard of wood per 1000 square feet of floor and 40% were diverted from landfills. So, 60% is available to be collected for energy. The breakdown in residential and commercial is as follows. Wood wastes collected from 11 residential homes yield an average of 1.8 pounds/ sq ft of wood waste or 7.2 cy/1000 square feet of new residential construction. The commercial buildings generate an average of slightly more than 1.6 lbs/sq ft of wood waste. (Gordon et al. 2003).

The second approach is to derive C&D waste first by applying empirical C&D waste generation rate per square foot to total square footage of residential and non-residential units built in each county, and then derive the total of wood waste by applying some wood rates. This approach is based on several studies. One key of such studies is the paper by Franklin Associates (1998). According to Franklin Associates estimates, waste generation rates from new construction of single and multi-family units were 4.58 lbs/sq ft and 3.99 lbs/ sq ft respectively and waste generation rate for demolition was 115 lbs/sq ft in 1997. Average waste generation rates for construction and demolition of non-residential structures were 3.89 lbs/ sq ft and 155 lbs/sq ft respectively. The study notes that waste assessment results should vary slowly with time because construction materials used and building construction practices remain relatively constant from year to year. It is also mentioned that composition of waste from demolished buildings, which were built over a range of years, should change even more slowly. As a result, applying these waste generation factors to newer data should be reasonable and consistent. Applying these factors to the total square footage of construction and demolition of residential and non-residential units would yield total waste estimates. Wood component is derived drawing upon a number of studies.

A publication by Alderman (1998) finds that nearly 34% of C&D debris was wood waste, and 11 % of the wood waste was recycled. A more recent study by Sendler (2003) finds the percentage of wood residues to be between 20% and 30%. Another study with regional scope by Bush et al. (1997) reports that of the total C&D debris received in the Midwest[6], 46% is wood. This falls into the 40%-50% range suggested by the National Association of Home Builders (NAHB) Research Center.

These approaches have been used by McKeever[7] and NCDENR (1998). However, unlike these studies, 2200 square feet[8] which is the size of a typical corporate-level home in Ohio cities including Columbus, Akron, Cincinnati, Cleveland, and Toledo is used instead of national or regional figures. The U.S. Census Bureau provides data that record the number of construction permits for each county in Ohio from 1996 to 2002. The annual average number of building

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[6] See figure 5 for the states containing in the Midwest region
[7] Op. Cit.
[8] Real State Journal, the Wall Street Journal Guide to Property.

permits along with the square footage of a typical corporate-level home in Ohio cities is used to estimate the total square footage in each county. The first approach is used to estimate wood residues from new construction since it yields more conservative estimates which are then converted into Btu equivalents.

Wood wastes from renovation of residential and non-residential units are estimated using an approach similar to that of NCDENR (1998). A conversion factor of 0.56 lbs of waste per dollar of renovation is used for both residential and non-residential structures. The US Census Bureau provides data on the value of residential repairs and improvements occurring in the Midwest for the years 2000, 2001, 2002 and 2003 (see Map 4.4 for the states composing the Midwest). Based on population estimates, the average of these figures is extrapolated to represent Ohio. Population estimates are also used for county level extrapolation. Applying the conversion factor to the dollar value of residential repairs and improvements allows estimating debris generated at county level. The percentage of wood is applied to determine the wood component (see Table 4.4). The average of 37.4% is used to estimate wood waste from renovation. To account for renovation wood wastes diverted from landfills, estimates from a project in San Diego, California are used. Only 49% of renovation wood waste is considered to be available for collection. The rest is either recycled or combusted. Because no data for demolition exists, only wood waste estimates from new construction and renovation are provided in the study. This limitation is unlikely to affect the results since concrete constitutes the largest component of building demolition debris. The final C&D wood estimates from new construction and renovation are converted into Btu equivalent. The results are displayed in Table 4.5. According to the table, Ohio generates an annual amount of 557,822 dry tons of usable wood from C&D. The largest part of usable C&D wood wastes is produced in northeastern Ohio. At the county level, Cuyahoga and Franklin generate the larger amounts of usable C&D wood wastes which are respectively 62,412 and 57,417 dry tons or 798.9 and 734.9 billion Btu's.

Table 4.4: Waste Rate Used in Calculation of Wood Waste from C&D

Sources of C&D wastes		Average waste generated (lbs/sq ft) by Franklin Associates	(%) of Wood waste by weight			
			by Franklin Assoc. (1998)	Used by NCDENR	NAHB	Average
Residential	Construction	4.38*	51	44.3	40-50	46.8
	Renovation	-	45	29.8	-	37.4
	Demolition	115*	42	32.3	-	37.15
Non-residential	Construction	3.89	16	18.8	-	17.4
	Renovation	-	-	18.1	-	18.1
	Demolition	155	16	24.9	-	20.45

***: Average for single and multi-family structures.**

Map 4.4: States included in the Midwest Region

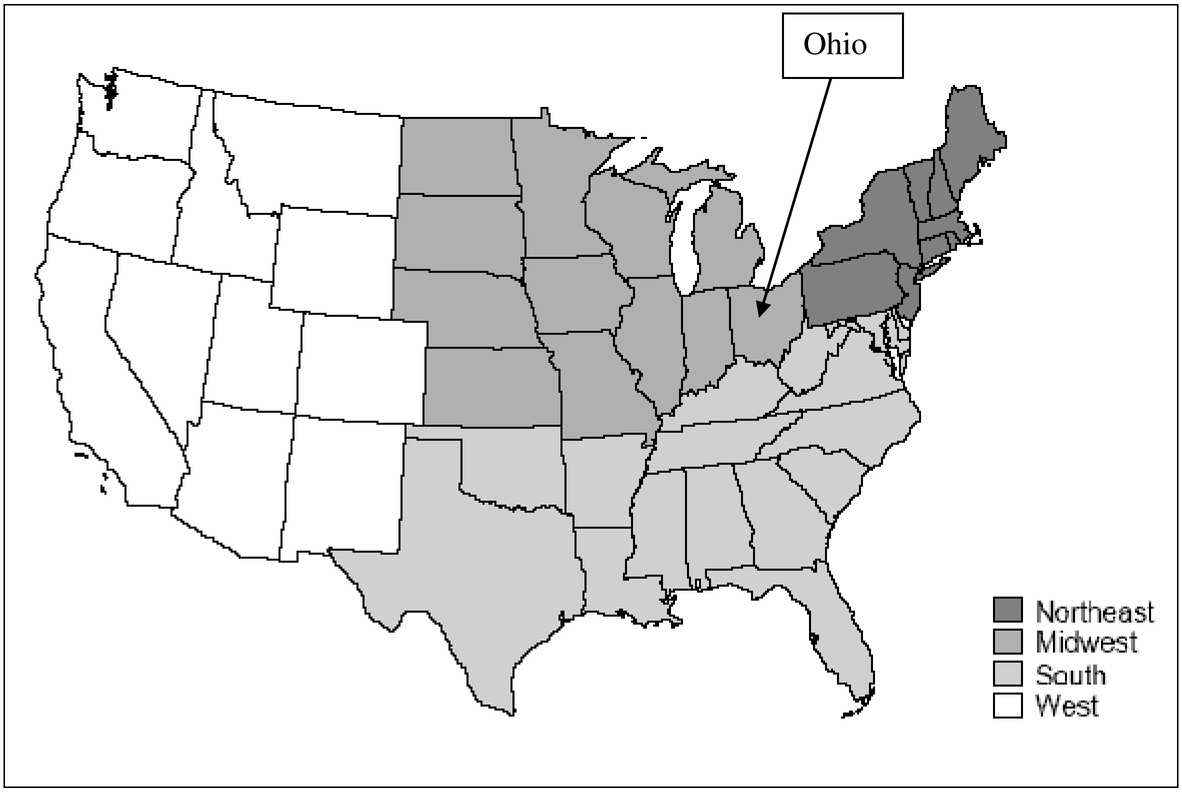


Table 4.5: Annual Average Estimates of C&D Wood Wastes by Ohio County and Geographic Unit (1996 -2002)

Regions	Counties	New Construction Waste (Dry Tons)		Renovation (Dry Tons)		Total		
		Gross	Usable	Gross	Usable	Usable*	Btu's	Rank
Central	Delaware	5,003	3,002	5,796	2,840	5,841	74.8	13
	Fairfield	1,682	1,009	5,785	2,835	3,843	49.2	20
	Franklin	16,488	9,893	47,525	23,287	33,180	424.7	1
	Licking	2,311	1,387	6,574	3,221	4,608	59.0	17
	Madison	391	235	1,773	869	1,104	14.1	57
	Pickaway	397	238	2,257	1,106	1,344	17.2	49
	Union	1,040	624	1,909	936	1,560	20.0	39
	Total Central	**27,312**	**16,387**	**71,619**	**35,093**	**51,480**	**659**	3
Eastern	Belmont	102	61	3,039	1,489	1,550	19.8	40
	Carroll	36	22	1,292	633	655	8.4	77
	Coshocton	27	16	1,621	794	810	10.4	69
	Guernsey	189	113	1,805	885	998	12.8	64
	Harrison	0	0	697	341	342	4.4	85
	Holmes	45	27	1,775	870	897	11.5	66
	Jefferson	115	69	3,137	1,537	1,607	20.6	38
	Monroe	4	2	651	319	322	4.1	86
	Tuscarawas	381	229	4,002	1,961	2,190	28.0	30
	Total Eastern	**899**	**540**	**18,020**	**8,830**	**9,369**	**120**	8
Northern	Erie	630	378	3,435	1,683	2,061	26.4	31
	Huron	387	232	2,629	1,288	1,520	19.5	41
	Lorain	3,026	1,816	12,707	6,227	8,042	102.9	9
	Lucas	2,534	1,520	19,823	9,713	11,234	143.8	6
	Ottawa	475	285	1,798	881	1,166	14.9	54
	Sandusky	331	199	2,695	1,321	1,519	19.4	42
	Seneca	374	225	2,520	1,235	1,459	18.7	43
	Wood	1,645	987	5,369	2,631	3,618	46.3	21
	Total Northern	**9,402**	**5,641**	**50,976**	**24,978**	**30,619**	**392**	4
North Central	Ashland	408	245	2,346	1,149	1,394	17.8	46
	Crawford	264	158	2,012	986	1,144	14.6	55
	Hardin	169	101	1,379	676	777	9.9	72
	Knox	695	417	2,485	1,217	1,635	20.9	36
	Marion	317	190	2,898	1,420	1,610	20.6	37
	Morrow	120	72	1,465	718	790	10.1	71
	Richland	971	583	5,598	2,743	3,326	42.6	23
	Wayne	1,177	706	4,937	2,419	3,125	40.0	24
	Wyandot	142	85	996	488	573	7.3	81
	Total Northcentral	**4,262**	**2,557**	**24,115**	**11,816**	**14,374**	**184**	5

Regions	Counties	New Construction Waste (Dry Tons)		Renovation (Dry Tons)		Total		
		Gross	Usable	Gross	Usable	Usable	Btu	Rank
Northeastern	Ashtabula	705	423	4,500	2,205	2,628	33.6	27
	Columbiana	233	140	4,867	2,385	2,525	32.3	29
	Cuyahoga	4,813	2,888	59,524	29,167	32,054	410.3	2
	Geauga	1,064	638	4,100	2,009	2,647	33.9	26
	Lake	1,917	1,150	9,989	4,895	6,045	77.4	12
	Mahoning	1,587	952	10,983	5,382	6,334	81.1	11
	Medina	3,075	1,845	7,054	3,457	5,302	67.9	16
	Portage	1,642	985	6,759	3,312	4,297	55.0	19
	Stark	2,566	1,540	16,476	8,073	9,613	123.0	8
	Summit	5,179	3,107	23,863	11,693	14,800	189.4	4
	Trumbull	1,082	649	9,679	4,743	5,392	69.0	15
	Total Northeastern	23,864	**14,318**	**157,795**	77,320	91,638	1,173	1
Northwestern	Allen	557	334	4,724	2,315	2,649	33.9	25
	Defiance	312	187	1,704	835	1,023	13.1	62
	Fulton	295	177	1,852	908	1,085	13.9	58
	Hancock	529	318	3,192	1,564	1,882	24.1	33
	Henry	182	109	1,280	627	736	9.4	74
	Paulding	179	107	858	421	528	6.8	82
	Putnam	166	99	1,517	743	843	10.8	68
	Van Wert	162	97	1,278	626	724	9.3	75
	Williams	329	197	1,693	830	1,027	13.1	61
	Total Northwestern	**2,711**	**1,627**	**18,098**	8,868	10,495	134	7
Southern	Adams	72	43	1,223	599	643	8.2	79
	Gallia	10	6	1,370	671	678	8.7	76
	Highland	105	63	1,831	897	960	12.3	65
	Jackson	272	163	1,443	707	870	11.1	67
	Lawrence	101	61	2,730	1,338	1,398	17.9	45
	Pike	68	41	1,230	603	644	8.2	78
	Ross	112	67	3,248	1,592	1,659	21.2	35
	Scioto	36	21	3,380	1,656	1,678	21.5	34
	Total Southern	**776**	**466**	**16,457**	8,064	8,530	109	9
Southeastern	Athens	107	64	2,810	1,377	1,441	18.4	44
	Hocking	30	18	1,250	613	631	8.1	80
	Meigs	32	19	1,014	497	516	6.6	83
	Morgan	3	2	648	317	319	4.1	87
	Muskingum	230	138	3,728	1,827	1,965	25.2	32
	Noble	71	42	613	301	343	4.4	84
	Perry	89	53	1,531	750	804	10.3	70
	Vinton	-	0	577	283	283	3.6	88
	Washington	77	46	2,728	1,337	1,383	17.7	47
	Total Southeastern	639	**383**	**14,899**	7,301	7,684	98	10

Regions	Counties	New Construction Waste (Dry Tons)		Renovation (Dry Tons)		Total		
		Gross	Usable	Gross	Usable	Usable	Btu	Rank
South West	Brown	141	85	1,912	937	1,021	13.1	63
	Butler	5,007	3,004	14,979	7,339	10,344	132.4	7
	Clermont	3,076	1,846	8,109	3,973	5,819	74.5	14
	Clinton	418	251	1,822	893	1,143	14.6	56
	Fayette	238	143	1,229	602	745	9.5	73
	Greene	1,969	1,181	6,601	3,235	4,416	56.5	18
	Hamilton	3,966	2,380	35,939	17,610	19,990	255.9	3
	Montgomery	3,379	2,028	24,099	11,809	13,836	177.1	5
	Preble	459	275	1,851	907	1,183	15.1	53
	Warren	5,584	3,350	7,932	3,887	7,237	92.6	10
	Total Southwestern	24,237	**14,542**	**104,472**	51,191	65,733	841	2
West	Auglaize	347	208	2,040	1,000	1,208	15.5	52
	Champaign	341	205	1,726	846	1,050	13.4	59
	Clark	760	456	6,256	3,066	3,522	45.1	22
	Darke	386	231	2,311	1,133	1,364	17.5	48
	Logan	490	294	2,026	992	1,286	16.5	51
	Mercer	276	166	1,786	875	1,041	13.3	60
	Miami	685	411	4,374	2,143	2,554	32.7	28
	Shelby	499	299	2,120	1,039	1,338	17.1	50
	Total Western	3,783	**2,270**	**22,639**	11,093	13,363	171	6
Ohio	**Total**	**97,884**	**58,731**	**499,091**	**244,555**	**303,286**	**3882.1**	-

***:** Parts may not equal whole because of rounding

4.4- Municipal solid waste

As stated earlier, municipal solid waste (MSW) is used to estimate wood residues from secondary wood manufacturers. MSW is a type of solid waste generated from community, commercial, and agricultural operations. This includes wastes from households, offices, stores and other non manufacturing activities. According to EPA (2001), MSW includes wastes such as product packaging, newspapers, office and classroom paper, bottles and cans, boxes, wood pallets, food scraps, grass clippings, clothing, furniture, appliances, automobile tires, consumer electronics, and batteries. This definition does not include wastes from construction and demolition debris and processing industries. While part of the MSW generated is recovered for recycling and combusting, much of it goes to landfills. However, much of the waste landfilled could be used to produce energy by various methods such pyrolysis, methane recovery, and combustion in utility broilers. Japan for example, incinerates more than 80% of its municipal solid waste.

In terms of solid waste, two studies are widely recognized as two of the mostly read and quoted: "The State of Garbage in America", published as an annual report in BioCycle and the "Municipal Solid Waste in the United States: Facts and Figures", which is the Franklin Associates' annual survey of generation and disposition of municipal solid wastes conducted on the U.S. EPA account. The two sources sometimes provide data displaying considerable gaps. For example, for the year 2000, figures reported by the two sources differ by about 170 million tons in terms of solid wastes generated in the US and by about 60 tons when it comes to recycling.

The methodology applied in the two reports may be one of the main reasons explaining such a big gap. For instance, Franklin Associates utilizes economic and population data to estimate MSW on a per capita basis and then extrapolates data to estimates the amount recycled, combusted and landfilled. However, BioCycle gathers tonnage data on MSW and asks states to estimate the percentage recycled, combusted and landfilled, though state reports vary widely regarding waste components. Some states may include construction/demolition debris or sewage sludge, while others may not. BioCycle method appears to be more consistent. Table 8 shows MSW information provided by the two entities.

In 2001, EPA estimated that on average, 29.7% of municipal solid waste was recovered to be recycled, 14.7% was combusted and the remaining 55.7% was land filled. Nation-wide, the average annual waste generation per day and per person from 1999 to 2010 is 4.71 pounds. In terms of percentage of each component in the MSW, the Franklin Associates' report provides more details, but only at a national level. Figure 4 displays the distribution of MSW with respect to each component. According the figure, MSW in 2001 contains mostly papers and plastics; wood accounts for only 5.7% on average.

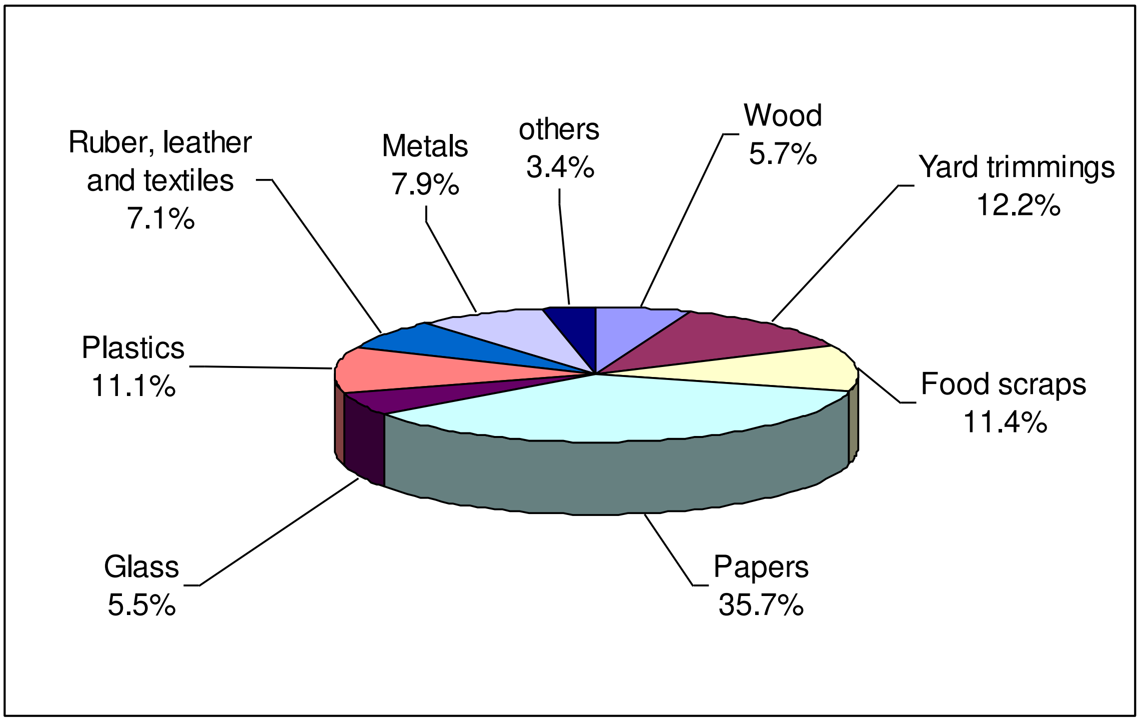
Wood is not the only type of waste that can be used for energy purposes. Burnable paper garbage, for example, can be effectively converted to briquette fuel that would provide millions of British thermal units (BTUs) of heat energy daily due to the fact that paper has a high heating value, approximately 7200 Btu's /lb. In fact, over 1/3 of Municipal Solid Waste (MSW) is biomass suitable for fuel, which could replace millions of barrels of imported oil a year. Paper wastes accounted for 35.5% of the nation's MSW in 2001.

In this study, to estimate wood and paper waste from MSW, local figures would be ideal. As stated earlier, national estimates sometimes do not reflect local conditions. Fortunately, Ohio EPA (2004) provides data for the state of Ohio on the amount of solid waste accepted by the landfills located in each solid waste management district for the year 2002 (See Table 4.8). Ohio has 52 solid waste management districts (SWMD) which are either single or groups of counties (See Map 4.5). The total amount of wastes disposed in each solid waste management district includes wastes received from in-district, out-of-district and out-of-state. Information is presented for counties maintaining active landfill sites for the year 2002 within each solid waste management district. Consequently, instead of using population data to estimate MSW, data on the amount MSW landfilled in each solid waste management district and each county holding active landfill sites were collected. The advantage of this method over a population based-method is that it captures wastes from other states. While Map 4.6 presents all counties with active landfill sites within each SWMD, Map 4.7 shows the solid wastes distribution among the counties that maintained one or more active landfill sites.

While Ohio EPA reports the amount of waste recycled, combusted and landfilled in each solid waste management district for the year 2002, it does not provide solid waste composition at the landfill sites. Resorting to national or regional estimates was needed to estimate wood and paper components of landfilled solid wastes. For example, between 1990 and 2001, the percentage of wood and paper of the municipal solid wastes landfilled in the US ranges from 7.0% to 7.4% and from 28.0% to 31.5% respectively (Franklin Associates 2001). See Table 4.7. Average of these values is used to estimate the wood and paper components of the solid wastes landfilled in each county.

In the year 2002, Ohio disposed about 20 million tons of waste. The Ohio average MSW landfills tip fee is $32.20 per ton, indicating a huge disposal burden for the state, even though the tip fee usually understates the average cost of waste disposal. Table 4.9 presents wood estimates from MSW for counties that maintained active landfill sites in 2002. It is worth noting that the fact that a county did not maintain active landfill sites in 2002 does not mean that the county did not generate any solid wastes. The solid waste was landfilled in another county where landfill sites are active. Among the counties that managed one or more active landfill sites, Gallia and Stark received the largest amounts of wastes (See Table 4.10) and thereby have the highest MSW wood wastes respectively 186,457 and 181,391 dry tons (air dry).

Figure 4.2: Composition of MSW before recycling



Source: Franklin Associates/ US EPA (2001)

Still energy can be recovered from materials other than wood and paper that remained in the MSW. Assuming a 30 to 40 percent moisture content and 65% efficiency, MSW have a potential of 4500 Btu's per pound. The potential Btu amount from MSW other than wood and paper is estimated using this conversion rate. To avoid double counting, the estimated quantity of energy related to wood and paper waste is taken into account. Therefore, energy equivalent for solid wastes other than wood and paper is computed as follows:

$[1-(0.072 + 0.303)]*Q_{MSW}*4,500*2,000$,

where 0.072 and 0.303 are the proportions of wood and paper respectively and Q_{MSW} is the quantity of MSW in tons. The result is reported in billions Btu's.

Table 4.10 displays the quantity of MSW and the Btu amount from paper and other solid wastes for counties that maintained active landfill sites in 2002. Again the presence of large amounts of solid wastes in Gallia and Stark Counties make them have the highest energy potential from MSW other than wood. Clinton is the County accounting for the smallest Btu amount. For these three counties the energy potential from MSW other than wood is respectively 25,866.2; 25,163.5 and 123.2 Btu's.

In terms of usable woody biomass in Ohio, Figure 4.3 through 4.5 and Map 4.8 present a summary of wood sources. From Figure 4.3, it can be seen that MSW accounts for 54%, forest and mill residues 35% and C&D 11%. Figure 4.4 indicates that the northeastern and southern regions provide the largest amount of woody biomass. The northwestern and western Ohio would be the geographical units with less amount of woody biomass. Figure 4.5 portrays the annual energy potential from woody biomass by region. At the county level, Map 4.8 shows the distribution of wood biomass potential among the counties. The reader is reminded that combining and reporting the results for all woody biomass sources in an annual basis rests on a critical assumption that forest and mill residues and MSW in Ohio would not vary significantly from one year to another.

Table 4.6: Comparison between BioCycle and Franklin Associates' SW Report

Level	Years	Reported MSW generated (millions)	Estimated MSW (millions)	Estimated MSW generated per person/year (ton)	MSW recycled (%)	MSW combusted WTE (%)	Landfilled (%)
BioCycle							
US	2000	409		1.45	32	7	61
	2001				32	7	61
	2002	483	369	1.31	26.7	7.7	65.6
Great Lakes	2000				27	5	68
	2002				27	5	68
Ohio	2000						
	2001	13.7	16.2	1.42[1]	23.5	0.0	76.5
	2002						
Franklin Associates for U.S. EPA							
US	2000		232	0.74	30.1	14.5	56.3
	2001		234		29.7	14.7	55.7
	2002						
Ohio EPA							
Ohio	2000		35.4	1.13	44		
	2001						

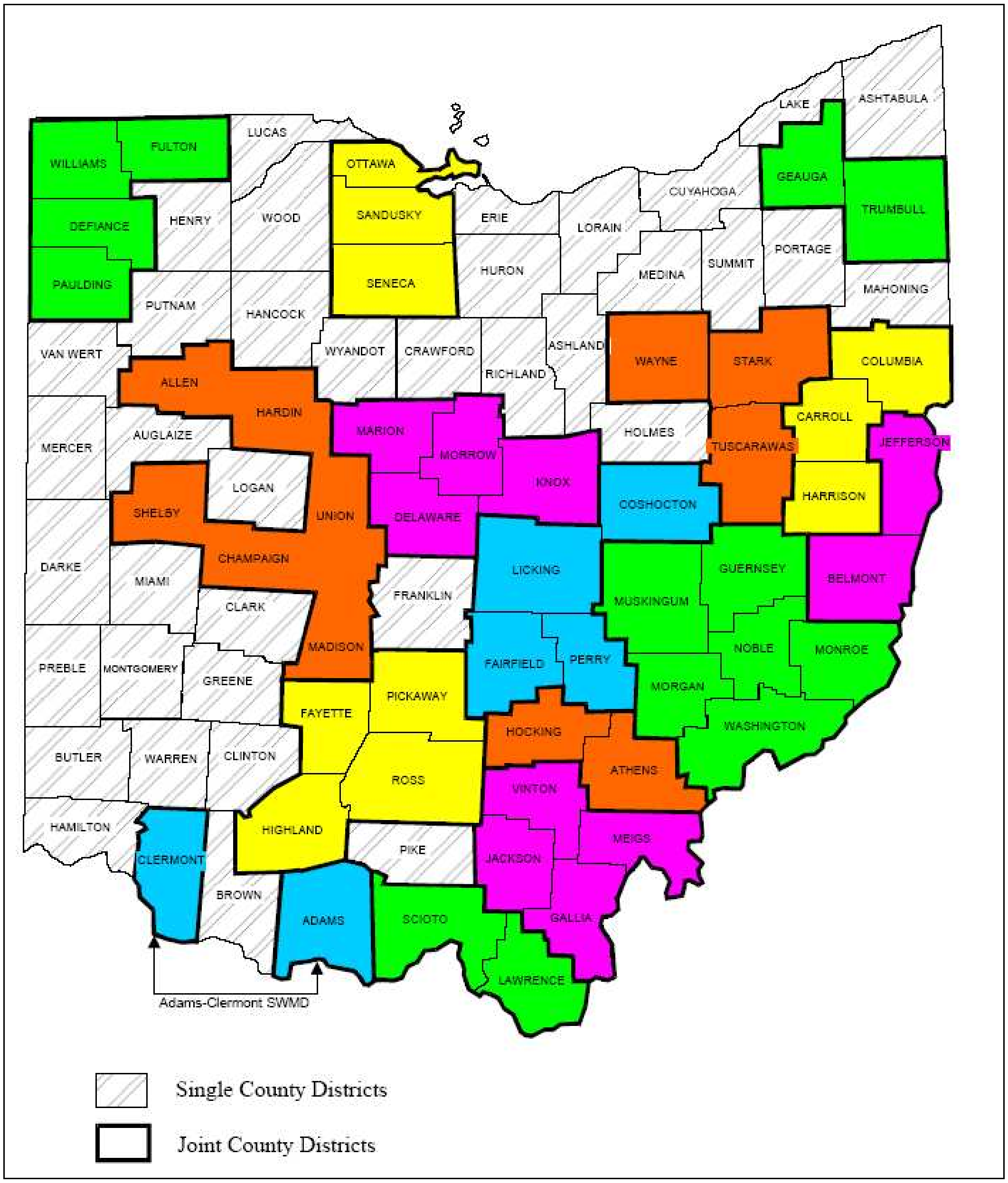
[1]: Industrial waste not included

Table 4.7: Percentage of Wood and Paper Discarded in Landfills between 1990-2001

	1990	**1995**	**1999**	**2000**	**2001**	**Average**
Paper and Paperboard	30.5	31.0	31.5	30.5	28.0	**30.3**
Wood	7.0	7.3	7.0	7.1	7.4	**7.2**

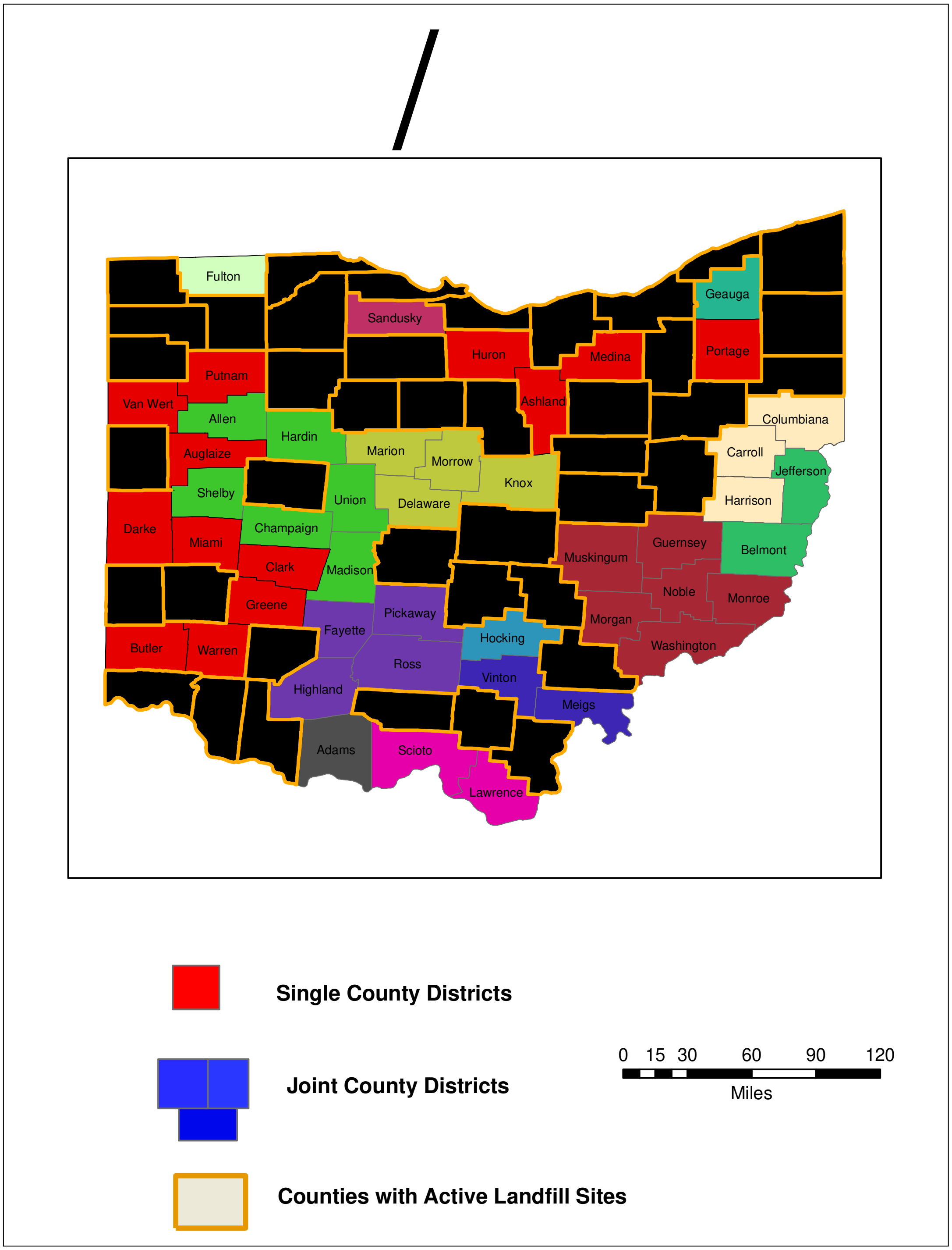
Source: Franklin Associates/EPA (2001)

Map 4.5: Ohio's Solid Waste Management Districts



Source: Ohio EPA

Map 4.6: Ohio Counties with Active Landfill Sites in 2002



Map 4.7: Solid Wastes Distribution among Counties with Active Landfill Sites (Tons)

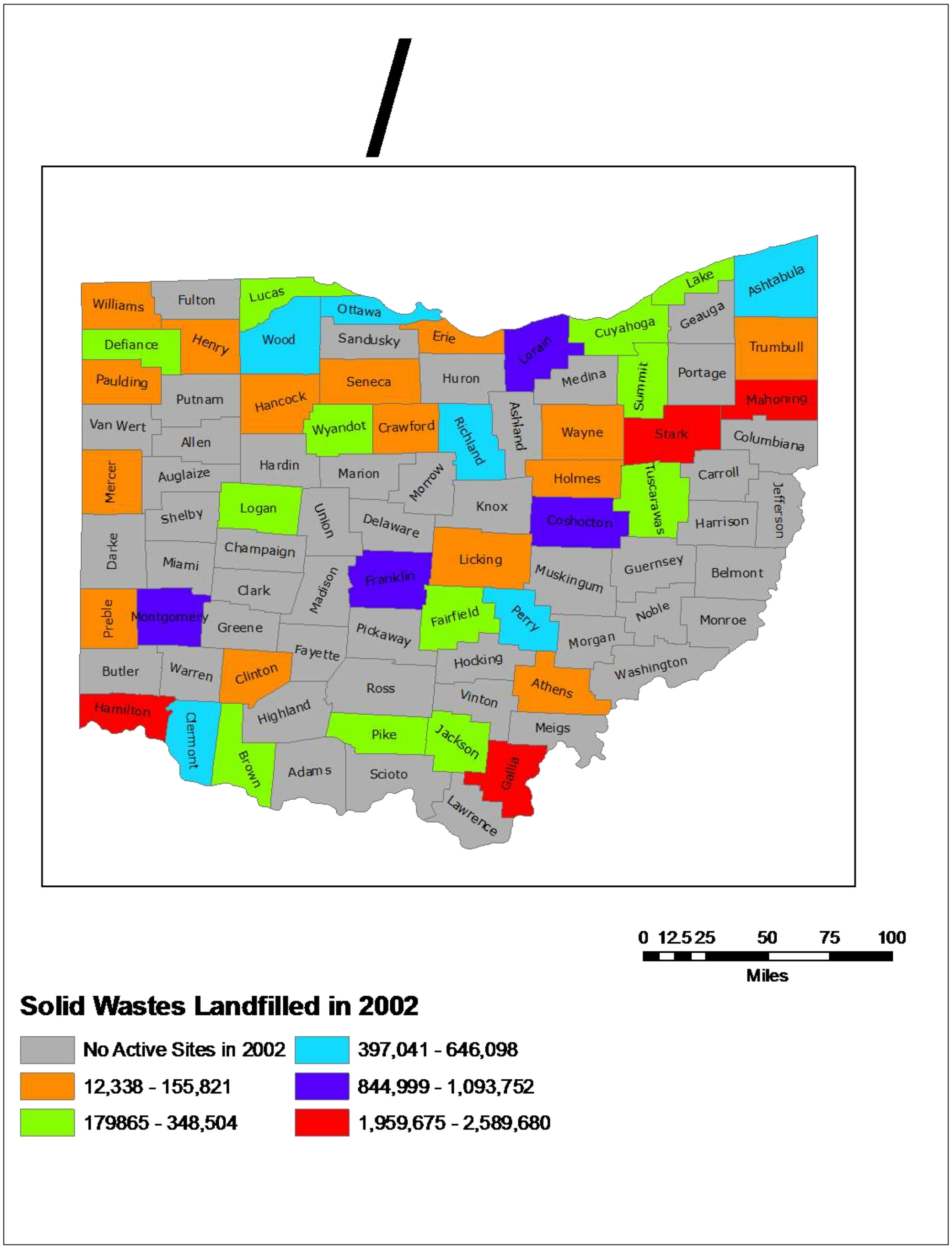


Table 4.8: Quantity of Municipal Solid Wastes Landfilled in Ohio by SWMD in 2002

Municipal Solid Waste District	Wastes (tons)	Number of Active Sites
Adams-Clermont Joint SWMD	411,306.00	1
Ashtabula County SWMD	529,793.51	3
Athens-Hocking SWMD	141,871.40	1
Brown County Solid Waste Authority SWMD	179,865.35	1
Clinton County SWMD	12,338.00	1
Coshocton-Fairfield-Licking-Perry SWMD	2,067,592.50	5
Crawford County SWMD	65,615.91	1
Cuyahoga County SWMD	185,286.49	3
Defiance-Fulton-Paulding-Williams SWMD	445,757.81	4
Erie County SWMD	108,169.51	1
Franklin County - SWACO SWMD	885,462.76	1
Gallia-Jackson-Meigs-Vinton SWMD	2,808,252.99	3
Geauga-Trumbull SWMD	71,145.00	1
Hamilton County SWMD	1,959,674.90	1
Hancock County SWMD	97,436.57	1
Henry County SWMD	21,281.99	1
Holmes County SWMD	42,160.56	1
Lake County SWMD	202,322.18	1
Logan County SWMD	348,504.39	1
Lorain County SWMD	914,163.86	1
Lucas County SWMD	197,559.21	2
Mahoning County SWMD	2,000,419.37	3
Mercer County SWMD	100,990.87	1
Montgomery County SWMD	844,999.83	2
Ottawa-Sandusky-Seneca SWMD	604,836.73	5
Pike County SWMD	254,256.51	1
Preble County SWMD	31,597.48	1
Richland County Solid Waste Authority SWMD	397,040.51	1
Stark-Wayne-Tuscarawas SWMD	2,986,963.28	7
Summit County Solid Waste Authority SWMD	188,894.28	1
Wood County SWMD	602,837.15	2
Wyandot County SWMD	285,856.31	1
Total	**19,994,253.21**	**60**

Source: Ohio EPA, 2004

Table 4.9: Wood Wastes Estimates from Primary and Secondary Wood Manufacturers

Regions	Counties	Mill Residues (Dry Tons)		Wood Wastes from MSW (Dry Tons)	Total		
		Gross	Usable	Usable	Usable	Btu (109)	Rank
Central	Delaware	3,910	553	0	553	7.1	49
	Fairfield	8,584	781	21,611	22,392	286.6	17
	Franklin	0	0	63,753	63,753	816.0	7
	Licking	0	0	1,987	1,987	25.4	40
	Madison	0	0	0	0	-	-
	Pickaway	0	0	0	0	-	-
	Union	0	0	0	0	-	-
	Total Central	**12,494**	**1,334**	**87,351**	**88,685**	**1,135**	**6**
Eastern	Belmont	54,656	2,402	0	2,402	30.7	38
	Carroll	0	0	0	0	-	60
	Coshocton	9,772	19	78,750	78,769	1,008.2	5
	Guernsey	0	0	0	0	-	-
	Harrison	0	0	0	0	-	-
	Holmes	75,740	951	3,036	3,987	51.0	37
	Jefferson	29,012	282	0	282	3.6	51
	Monroe	0	0	0	0	-	-
	Tuscarawas	29,012	203	24,173	24,376	312.0	16
	Total East	**198,192**	**3,857**	**105,959**	**109,816**	**1,406**	**5**
Northern	Erie	6,954	1,196	7,788	8,984	115.0	30
	Huron	0	0	0	0	-	-
	Lorain	0	0	65,820	65,820	842.5	6
	Lucas	0	0	14,224	14,224	182.1	23
	Ottawa	5,953	19	36,500	36,519	467.4	12
	Sandusky	0	0	0	0	-	-
	Seneca	0	0	7,048	7,048	90.2	33
	Wood	0	0	43,404	43,404	555.6	10
	Total North	**12,907**	**1,215**	**174,785**	**176,000**	**2,253**	**4**
North central	Ashland	18,375	1,266	0	1,266	16.2	44
	Crawford	10,497	12	4,724	4,736	60.6	35
	Hardin	0	0	0	0	-	
	Knox	7,511	396	0	396	5.1	50
	Marion	0	0	0	0	-	-
	Morrow	0	0	0	0	-	-
	Richland	0	0	28,587	28,587	365.9	14
	Wayne	0	0	9,497	9,497	121.6	29
	Wyandot	0	0	20,582	20,582	263.4	18
	Total North central	**36,383**	**1,674**	**63,390**	**65,064**	**833**	**7**

Regions	Counties	Mill Residues (Dry Tons)		Wood Wastes from MSW (Dry Tons)	Total		
		Gross	Usable	Usable	Usable	Btu (10^9)	Rank
North Eastern	Ashtabula	7,682	95	38,145	38,240	489.5	11
	Columbiana	3,270	0	0	0	-	-
	Cuyahoga	0	0	13,341	13,341	170.8	25
	Geauga	16,190	640	0	640	8.2	47
	Lake	0	0	14,567	14,567	186.5	22
	Mahoning	14,260	2,188	144,030	146,218	1,871.6	3
	Medina	0	0	0	0	-	-
	Portage	0	0	0	0	-	-
	Stark	45,195	1,964	181,391	183,355	2,346.9	2
	Summit	0	0	13,600	13,600	174.1	24
	Trumbull	35,017	413	5,122	5,535	70.9	34
	Total Northeast	**121,614**	**5,300**	**410,197**	**415,497**	**5,318**	**1**
North Western	Allen	23,296	1,346	0	1,346	17.2	43
	Defiance	8,869	168	16,690	16,858	215.8	20
	Fulton	274	39	0	39	0.5	55
	Hancock	3,699	957	7,015	7,972	102.0	31
	Henry	0	0	1,532	1,532	19.6	41
	Paulding	0	0	4,186	4,186	53.6	36
	Putnam	0	0	0	0	-	-
	Van Wert	0	0	0	0	-	-
	Williams	0	0	11,219	11,219	143.6	27
	Total Northwest	**36,138**	**2,510**	**40,642**	**43,152**	**552**	**9**
South	Adams	10,212	590	0	590	7.6	48
	Gallia	14,537	384	186,457	186,841	2,391.6	1
	Highland	0	0	0	0	-	-
	Jackson	26,119	649	15,737	16,386	209.7	21
	Lawrence	0	0	0	0	-	-
	Pike	50,253	1,289	18,306	19,595	250.8	19
	Ross	8,124	32	0	32	0.4	56
	Scioto	27,619	6	0	6	0.1	58
	Total South	**136,864**	**2,950**	**220,501**	**223,451**	**2,860**	**3**
South Eastern	Athens	7,164	16	10,215	10,231	131.0	28
	Hocking	33,714	662	0	662	8.5	46
	Meigs	41,523	1,471	0	1,471	18.8	42
	Morgan	0	0	0	0	-	-
	Muskingum	7,964	26	0	26	0.3	-
	Noble	0	0	0	0	-	-
	Perry	11,407	6	46,519	46,525	595.5	9
	Vinton	178,129	101	0	101	1.3	54
	Washington	77,792	0	0	0	-	-
	Total Southeast	**357,693**	**2,282**	**56,734**	**59,016**	**755**	**8**

Regions	Counties	Mill Residues (Dry Tons)		Wood Wastes from MSW (Dry Tons)	Total		
		Gross	Usable	Usable	Usable	Btu	Rank
South Western	Brown	6,011	51	12,950	13,001	166.4	26
	Butler	13,495	143	0	143	1.8	52
	Clermont	0	0	29,614	29,614	379.1	13
	Clinton	7,896	0	888	888	11.4	45
	Fayette	0	0	0	0	-	-
	Greene	0	0	0	0	-	-
	Hamilton	0	0	141,097	141,097	1,806.0	4
	Montgomery	0	0	60,840	60,840	778.8	8
	Preble	0	0	2,275	2,275	29.1	39
	Warren	0	0	0	0	-	87
	Total South West	**27,402**	**194**	**247,664**	**247,858**	**3,173**	**2**
Western	Auglaize	0	0	0	0	-	-
	Champaign	3,256	117	0	117	1.5	53
	Clark	0	0	0	0	-	-
	Darke	0	0	0	0	-	-
	Logan	0	0	25,092	25,092	321.2	15
	Mercer	0	0	7,271	7,271	93.1	32
	Miami	0	0	0	0	-	-
	Shelby	0	0	0	0	-	-
	Total West	**3,256**	**117**	**32,364**	**32,481**	**416**	**10**
Ohio	**Total**	**942,943**	**21,433**	**1,439,586**	**1,461,019**	**18,701**	

Table 4.10: Energy estimates from Paper and Other MSW in Ohio Counties

Regions	Counties	MSW (Tons)	Paper Wastes	Btu	MSW BTU*	Total Btu (10^9)	Total Rank
Central	Delaware		0	-	-	-	-
	Fairfield	300,148.58	90,945	1,309.6	1,688.3	2,997.9	17
	Franklin	885,462.76	268,295	3,863.5	4,980.7	8,844.2	7
	Licking	27,594.00	8,361	120.4	155.2	275.6	39
	Madison		0	-	-	-	-
	Pickaway		0	-	-	-	-
	Union		0	-	-	-	-
	Total Central	**1213205.34**	**367,601**	**5,293**	**6,824.3**	**12,117.7**	**6**
Eastern	Belmont		0	-	-	-	-
	Carroll		0	-	-	-	-
	Coshocton	1093752.04	331,407	4,772.3	6,152.4	10,924.6	5
	Guernsey		0	-	-	-	-
	Harrison		0	-	-	-	-
	Holmes	42,160.56	12,775	184.0	237.2	421.1	37
	Jefferson		0	-	-	-	-
	Monroe		0	-	-	-	-
	Tuscarawas	335,734.00	101,727	1,464.9	1,888.5	3,353.4	16
	Total East	**1,471,646.60**	**445,909**	**6,421**	**8,278.0**	**14,699.1**	**5**
Northern	Erie	108,169.51	32,775	472.0	608.5	1,080.4	30
	Huron		0	-	-	-	-
	Lorain	914,163.86	276,992	3,988.7	5,142.2	9,130.9	6
	Lucas	197,559.21	59,860	862.0	1,111.3	1,973.3	23
	Ottawa	506943	153,604	2,211.9	2,851.6	5,063.4	12
	Sandusky		0	-	-	-	-
	Seneca	97,893.73	29,662	427.1	550.7	977.8	32
	Wood	602,837.15	182,660	2,630.3	3,391.0	6,021.3	10
	Total North	**2,427,566.46**	**735,553**	**10,592**	**13,655.1**	**24,247.0**	**4**
North Central	Ashland		0	-	-	-	-
	Crawford	65,615.91	19,882	286.3	369.1	655.4	35
	Hardin		0	-	-	-	-
	Knox		0	-	-	-	-
	Marion		0	-	-	-	-
	Morrow		0	-	-	-	-
	Richland	397,040.51	120,303	1,732.4	2,233.4	3,965.7	14
	Wayne	131908.09	39,968	575.5	742.0	1,317.5	29
	Wyandot	285,856.31	86,614	1,247.2	1,607.9	2,855.2	18
	Total Northcentral	**880,420.82**	**266,768**	**3,841**	**4,952.4**	**8,793.8**	**7**

Regions	Counties	MSW (Tons)	Paper wastes	BTU	MSW BTU*	Total	
						Btu (10^9)	Rank
North Eastern	Ashtabula	529,793.51	160,527	2,311.6	2,980.1	5,291.7	11
	Columbiana		0	-	-	-	-
	Cuyahoga	185,286.49	56,142	808.4	1,042.2	1,850.7	25
	Geauga		0	-	-	-	-
	Lake	202,322.18	61,304	882.8	1,138.1	2,020.8	22
	Mahoning	2,000,419.37	606,127	8,728.2	11,252.4	19,980.6	3
	Medina		0	-	-	-	-
	Portage		0	-	-	-	-
	Stark	2519321.19	763,354	10,992.3	14,171.2	25,163.5	2
	Summit	188,894.28	57,235	824.2	1,062.5	1,886.7	24
	Trumbull	71,145.00	21,557	310.4	400.2	710.6	34
	Total Northeastern	**5,697,182.02**	**1,726,246**	**24,858**	**32,046.6**	**56,904.6**	**1**
North Western	Allen		0	-	-	-	-
	Defiance	231802.93	70,236	1,011.4	1,303.9	2,315.3	20
	Fulton		0	-	-	-	-
	Hancock	97,436.57	29,523	425.1	548.1	973.2	33
	Henry	21,281.99	6,448	92.9	119.7	212.6	40
	Paulding	58,134.00	17,615	253.7	327.0	580.7	36
	Putnam		0	-	-	-	-
	Van Wert		0	-	-	-	-
	Williams	155,820.88	47,214	679.9	876.5	1,556.4	27
	Total Northwestern	**564,476.37**	**171,036**	**2,463**	**3,175.2**	**5,638.1**	**9**
Southern	Adams		0	-	-	-	-
	Gallia	2589679.74	784,673	11,299.3	14,566.9	25,866.2	1
	Highland		0	-	-	-	-
	Jackson	218,573.25	66,228	953.7	1,229.5	2,183.2	21
	Lawrence		0	-	-	-	-
	Pike	254,256.51	77,040	1,109.4	1,430.2	2,539.6	19
	Ross		0	-	-	-	-
	Scioto		0	-	-	-	-
	Total Southern	**3,062,509.50**	**927,940**	**13,362**	**17,226.6**	**30,589.0**	**3**
South Eastern	Athens	141,871.40	42,987	619.0	798.0	1,417.0	28
	Hocking		0	-	-	-	-
	Meigs		0	-	-	-	-
	Morgan		0	-	-	-	-
	Muskingum		0	-	-	-	-
	Noble		0	-	-	-	-
	Perry	646,097.88	195,768	2,819.1	3,634.3	6,453.4	9
	Vinton		0	-	-	-	-
	Washington		0	-	-	-	-
	Total Southeastern	**787,969.28**	**238,755**	**3,438**	**4,432.3**	**7,870.4**	**8**

Regions	Counties	MSW (Tons)	Paper wastes	Btu	MSW Btu*	Total	
						Btu (10^9)	Rank
South Western	Brown	179,865.35	54,499	784.8	1,011.7	1,796.5	26
	Butler		0	-	-	-	-
	Clermont	411,306.00	124,626	1,794.6	2,313.6	4,108.2	13
	Clinton	12,338.00	3,738	53.8	69.4	123.2	41
	Fayette		0	-	-	-	-
	Greene		0	-	-	-	-
	Hamilton	1,959,674.90	593,781	8,550.5	11,023.2	19,573.6	4
	Montgomery	844,999.83	256,035	3,686.9	4,753.1	8,440.0	8
	Preble	31,597.48	9,574	137.9	177.7	315.6	38
	Warren		0	-	-	-	-
	Total Southwestern	**3,439,781.56**	**1,042,254**	**15,008**	**19,348.8**	**34,357.2**	**2**
Western	Auglaize		0	-	-	-	-
	Champaign		0	-	-	-	-
	Clark		0	-	-	-	-
	Darke		0	-	-	-	-
	Logan	348,504.39	105,597	1,520.6	1,960.3	3,480.9	15
	Mercer	100,990.87	30,600	440.6	568.1	1,008.7	31
	Miami		0	-	-	-	-
	Shelby		0	-	-	-	-
	Total West	**449495.26**	**136,197**	**1,961**	**2,528.4**	**4,489.6**	**10**
Ohio	**Total**	**19,994,253.21**	**6,058,259**	**87,238.9**	**112,467.7**	**199,706.6**	

*Not including wood and paper

Figure 4.3: Ohio Woody Biomass by Source (Thousand Tons and Percentage)

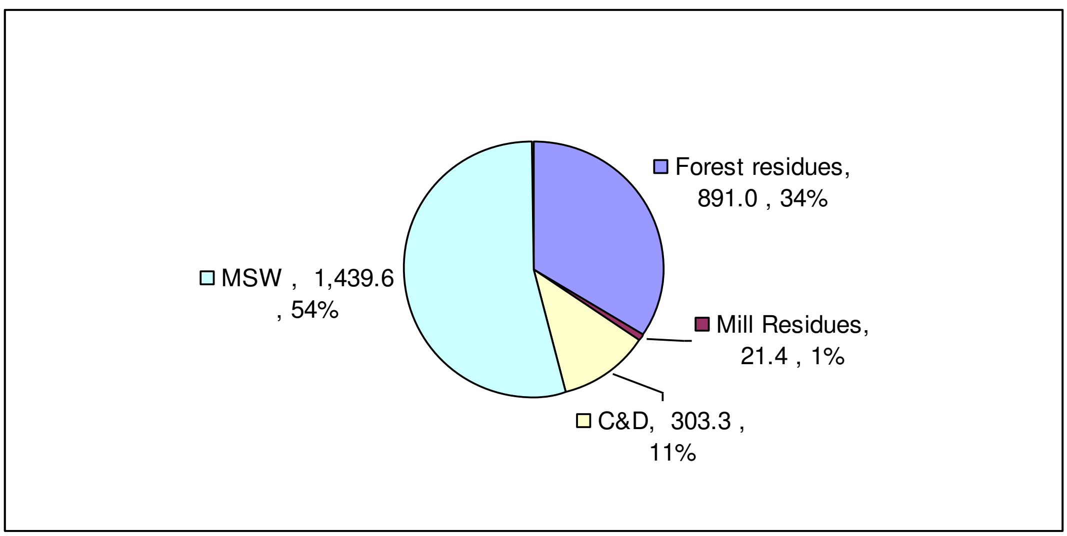


Figure 4.4: Ohio Sources of Wood Wastes by Geographical Unit

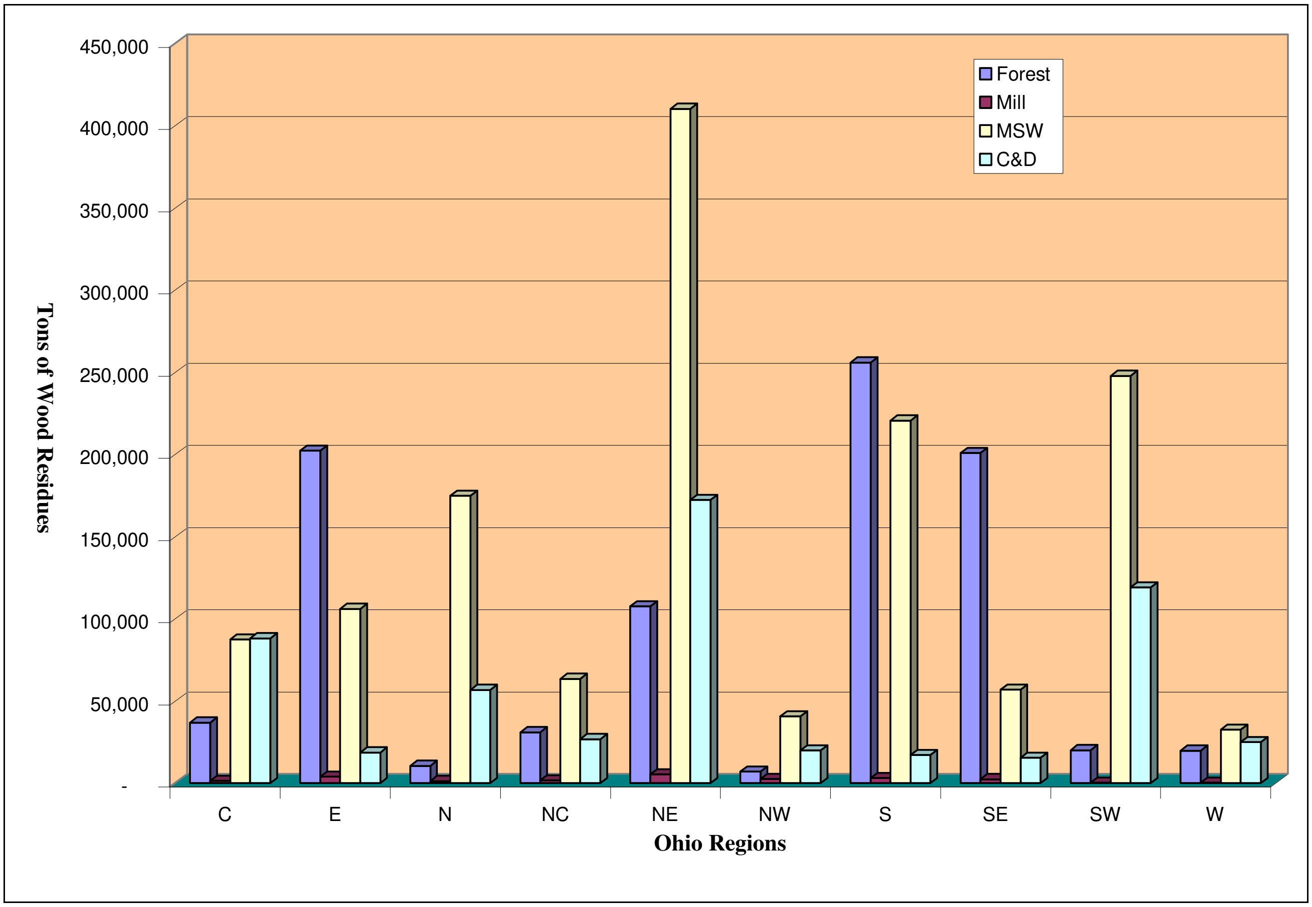
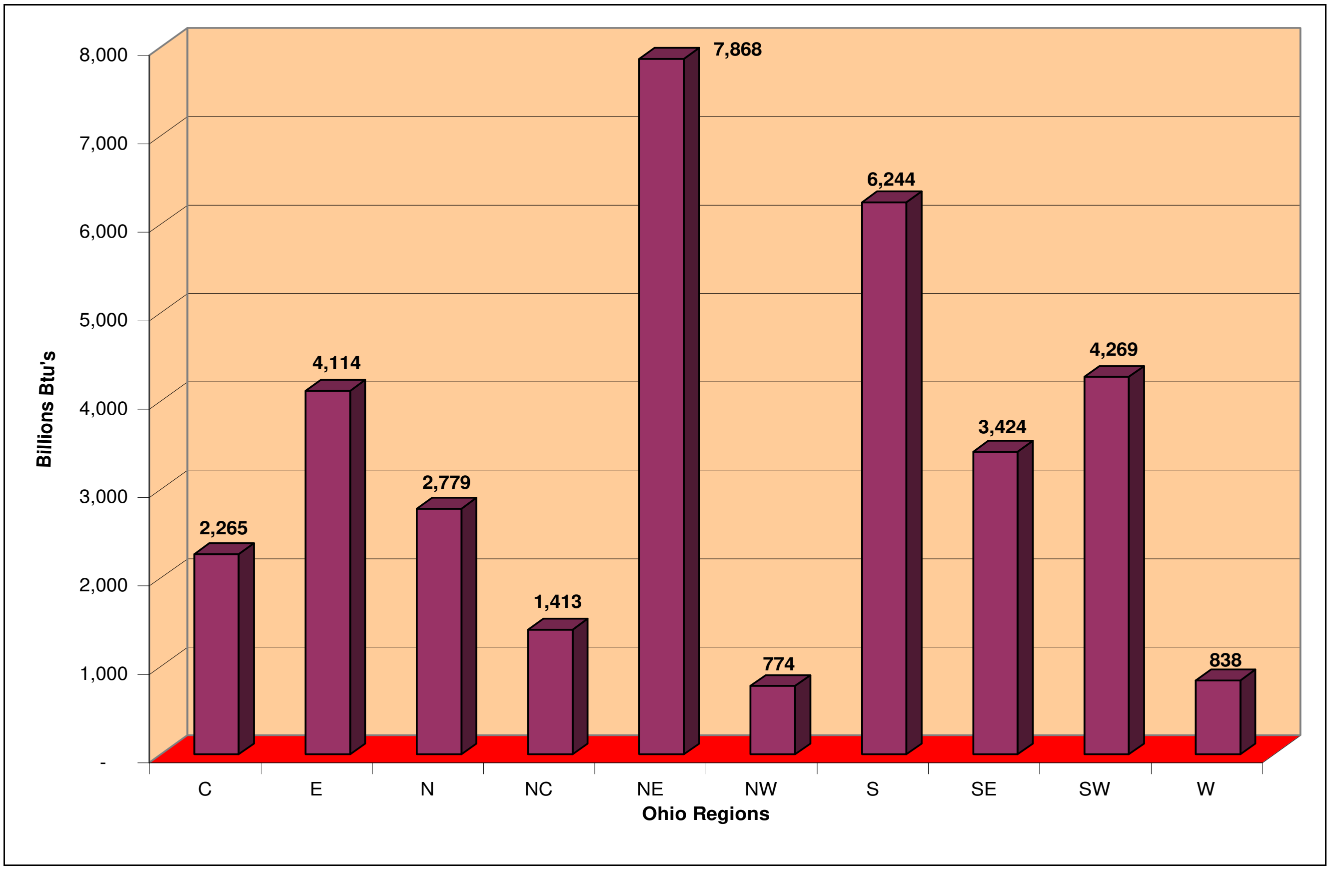
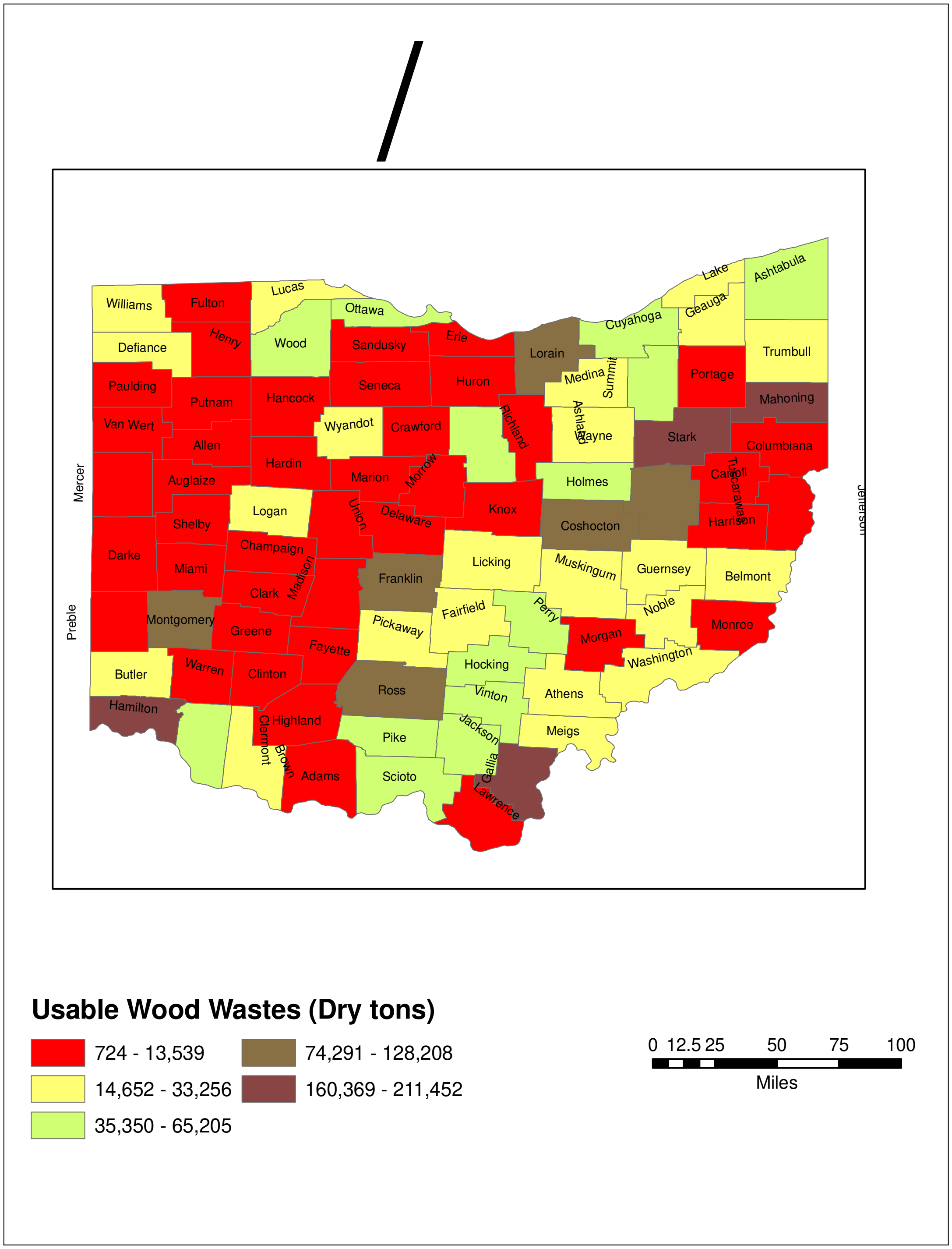


Figure 4.5: Annual Potential Energy from Wood Sources by Geographical Unit



Map 4.8: Distribution of Usable Wood Wastes among Ohio Counties



5.-Methane from livestock manure

In the US, the major sources of methane include landfills, livestock and natural gas and petroleum systems. Domesticated animals are a source of methane in two ways: from their digestive process and from their manure. Since collecting methane produced from animal enteric fermentation for energy purposes is a bit more challenging, this study is concerned with methane emitted from manure management. Manure could be a serious environmental concern if not managed and used properly. Methane from manure management is mostly produced through manure storage. When exposed to limited aeration which prevents complete decomposition to carbon dioxide, stockpiled manure leads to methane production. Higher amount of methane is produced when manure is stored in liquid form because of poor aeration. As a result, pig manure generally stored as slurry generates high amount of methane. According to US EPA, methane accounts for 16% of global greenhouse emissions. As a result, using methane emissions for energy can be profitable both economically and environmentally. Because methane is a high Btu gas, 24,000 Btu/lb, burning it as a fuel represents the most economic and environmentally friendly alternative to reduce emissions of green house gases.

A number of methods can be used to recover energy from manure including anaerobic digestion, thermal oxidation/gasification, direct combustion, liquid fuels (ethanol from gasification), etc…. For example, using the anaerobic digestion method, raw manure from about 700 cows has been used to produce about 100 kW of electricity in Iowa (Meyer 2003).

The methodology used by US EPA is adapted here to estimate methane from livestock manure. The steps involves in the calculation of methane are as follows:

a) Collect of animal population data

Annual animal population data were collected from the USDA National Agricultural Statistics Services for 1997 through 2003 for beef cattle, dairy cattle and swine. No data were available at county level for poultry. As a result, a 7-year average number of heads of beef and dairy cattle and swine is used in the calculation of methane.

b) Determine the amount of volatile solids produced by each type of animal

Animal population by type, the typical animal mass, and the amount of volatile solids produced per typical animal mass unit and per year are required to determine the amount of volatile solids produced by each type of animal. Amount in kilograms of volatile solids per day and per 1000kg of mass for many subgroups within the beef and dairy cattle groups are given by Peterson et al. 2003. For subgroups within the swine category, this information was taken from USDA (1996). Because data on animal population provided by the USDA National Agricultural Statistics Services are not broken down in subgroups at county level, the volatile solids amounts provided for subcategories are averaged to represent each group. The averages which are then converted into pounds of volatile solids per pound of mass per year are used as volatile solids for each animal group (see Table 5.1).

The typical animal mass for each animal group is given by the Midwest Plan Service, but broken down in mature cows and replacements for beef and dairy and in breeding and market for swine. The typical animal mass for the subgroups are averaged to represent each group (See Table 5.2). The following equation is used to calculate the volatile solids produced by each type of animal:

VS_i (lbs.) = N_i *TAM_i*vs_i, (2)

where

Ni (head) = Number of animal of type i

TAMi (lbs./head) = Typical animal mass for type i

vsi (lbs./lb of mass/year) = Volatile solids per pound of mass per year

c) Use the appropriate methane conversion factors and maximum methane producing capacity per pound of volatile solids.

The amount methane to be produced depends on how manure is managed. The methane producing capacity is animal specific while the methane conversion factor is inherent in a manure management system. USEPA (2004) provides information on 2002 manure distribution among waste management systems for each type of animal in Ohio. This distribution is assumed to be the same for each county.

d) Estimate methane emissions.

The following equations are used to estimate methane emissions:

$$M_{ij} = VSi*\beta i*MCF_j*P_{ij}*1.4564 \qquad (3)$$

$$M_i = \Sigma_j(_{VSi}*\beta_i*MCF_j*P_{ij}*1.4564) \qquad (4)$$

$$M_i = VS_i*\beta_i* 1.4564*\sum_j(MCF_j*P_{ij}) \qquad (5)$$

$$M_i = (VS_i*\beta_i* WMCF_i *1.4564) / 2000 \qquad (6)$$

where,

i = Each animal type

j = Each manure management system

M_{ij} = Methane emissions from animal type i on system j

M_i = Methane emission from animal of type i on all systems

β_i = Maximum methane producing capacity per pound of volatile solid of animal type i (m3/lb of VS)

MCF_j = Methane conversion factor for system j

P_{ij} = Percent of manure of animal type i managed in system j

$WMCF_i$ = $\sum_j(MCF_j * P_{ij})$: Weighted methane conversion factor for animal type i

1.4564 = Conversion factor of m^3 to pounds

2000 = Conversion factor of pounds to short tons

β_i and $WMCF_i$ values are taken from Hashimoto (1984) and USEPA (2003 and 2004). See table 5.3. Manure management systems in Ohio for 2001 and 2002 can be found in USEPA (2003 and 2004).

The solution to Equation 6 is presented in Figures 5.1 and 5.2, Map 5.1 and Table 5.4. Figure 5.1 shows that in terms of sources of methane potential in Ohio swine manure ranks first followed by dairy and then beef cattle. This result is as expected since swine manure is generally managed in liquid form where aeration is limited. As can be seen in Figure 5.2, the highest methane potential concentrates in Western and Northcentral Ohio. At county level, Table 5.4 pinpoints the distribution of annual average methane potential among Ohio counties. Finally, map 5.1 displays this distribution spatially.

Table 5.1: Livestock Volatile Solids for Ohio in 2002

Animal Type	Volatile Solids[1] (kgs of VS/day/1000kg of Mass)	Average Volatile Solids (lbs. of VS /lb of mass/per year)
Beef Cattle		
NOF[2] Cattle	6.63	
NOF Heifers	7.04	
NOF Steers	7.46	
Feedlot Heifers	3.35	
Feedlot Steers	3.28	
Average	**5.53**	**2.03**
Dairy Cattle		
Dairy Cow	8.38	
Dairy Heifers	6.82	
Average	**7.525**	**2.75**
Swine[3]		
Market Swine <60 lbs	8.80	
Market Swine <60 lbs	5.40	
Breeding Swine	2.60	
Average	**5.6**	**2.04**

Source [1]: Peterson et al. 2003
[2]: Not on Feed
[3]: USDA 1996

Table 5.2: Typical Animal Mass

<table>
<tr><th rowspan="2">Animal Type</th><th colspan="3">Typical Animal Mass (TAM)
(lbs./head)</th></tr>
<tr><th>Mature Cows</th><th>Replacements</th><th>Average</th></tr>
<tr><td>Beef Cattle</td><td>1,102</td><td>794</td><td>948</td></tr>
<tr><td>Dairy</td><td>1345</td><td>903</td><td>1124</td></tr>
<tr><td rowspan="2">Swine</td><td>Breeding</td><td>Market</td><td rowspan="2">250</td></tr>
<tr><td>399</td><td>101</td></tr>
</table>

Source: Midwest Service Plan

Table 5.3: Weighted Methane Conversion Factors for Ohio

<table>
<tr><th rowspan="2">Animal Type</th><th rowspan="2">β (m³ of CH4/ lb of VS)[1]</th><th colspan="3">WMCF (%)[2]</th></tr>
<tr><th>2001</th><th>2002</th><th>Average</th></tr>
<tr><td>Beef Cattle</td><td>0.15</td><td>1.7</td><td>1.7</td><td>1.7</td></tr>
<tr><td>Dairy Cattle</td><td>0.11</td><td>10.2</td><td>10.7</td><td>10.5</td></tr>
<tr><td>Swine</td><td>0.22</td><td>30.3</td><td>32</td><td>31.2</td></tr>
</table>

Source: [1]**:** Hashimoto 1984
[2]**:** USEPA 2003b, 2004

Figure 5.1: Methane from Livestock Manure by Animal Type (in Tons and %)

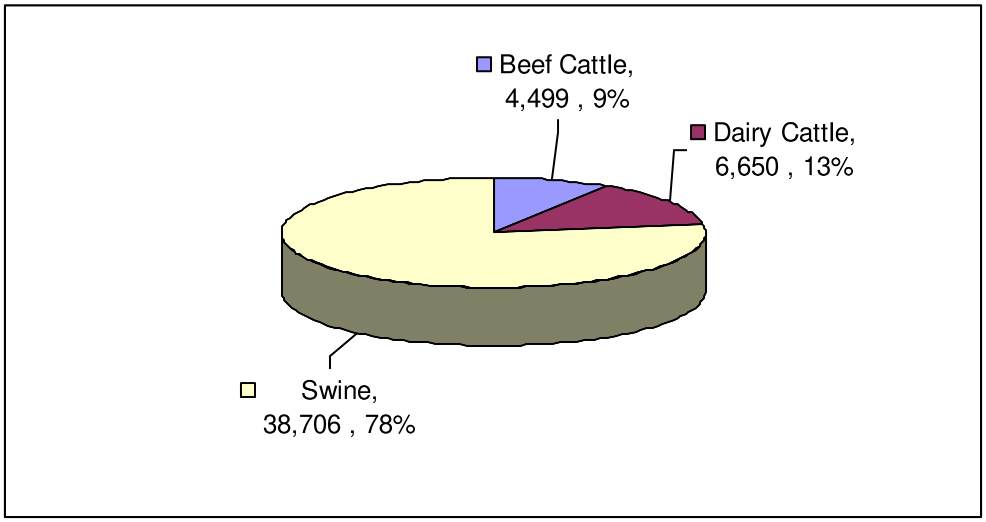
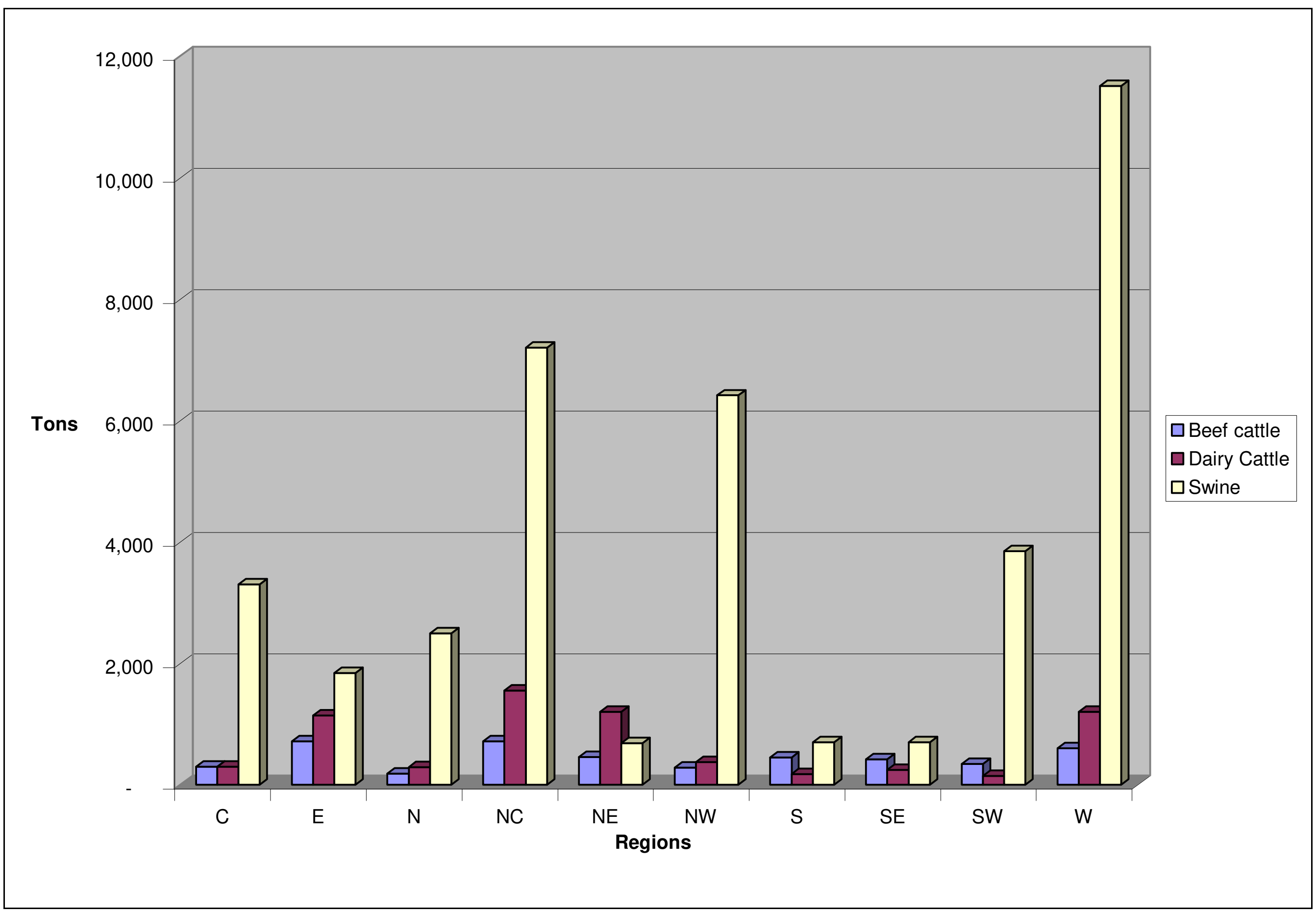


Figure 5.2: Methane by Animal Type and Geographical Unit



Map 11: Methane from Livestock Manure by County

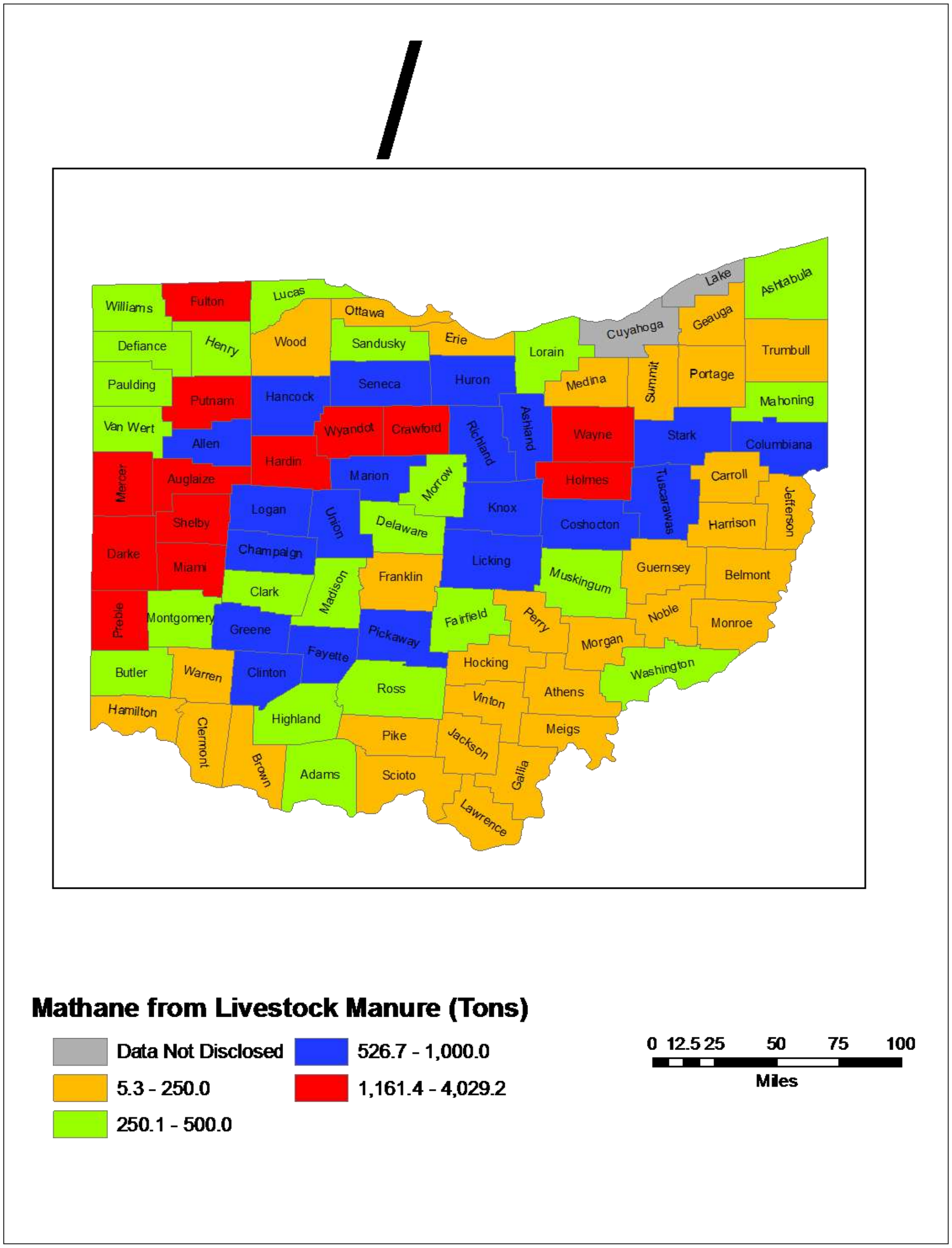


Table 5.4: Annual Average Methane Estimates from Livestock Manure (1997-2003)
(VS in lbs and Methane in tons)

Regions	Counties	Beef Cattle		Dairy Cattle		Swine		Total		
		Volatile Solids	Methane	Volatile Solids	Methane	Volatile Solids	Methane	Methane	Btu's	Rank
Central	Delaware	11,436,672	21	3,322,825	28	7,926,857	393	441.8	21.2	39
	Fairfield	32,660,496	61	4,901,443	41	8,007,000	397	498.5	23.9	34
	Franklin	5,333,448	10		-	2,120,143	105	114.9	5.5	71
	Licking	44,866,944	83	12,761,414	107	9,150,857	453	643.9	30.9	26
	Madison	23,670,612	44	5,475,486	46	7,650,000	379	468.9	22.5	37
	Pickaway	21,058,872	39	3,168,275	27	13,799,143	683	749.2	36.0	20
	Union	23,835,564	44	6,314,471	53	18,075,857	895	992.7	47.6	14
	Total Central	**162,862,608**	**302**	**35,943,914**	**302**	**66,729,857**	**3,305**	**3,910**	**188**	**5**
Eastern	Belmont	41,925,300	78	8,257,386	69		-	147.3	7.1	67
	Carroll	32,990,400	61	11,613,329	98	510,000	25	184.2	8.8	60
	Coshocton	44,839,452	83	12,982,200	109	14,760,857	731	923.5	44.3	16
	Guernsey	40,358,256	75	4,415,714	37	1,894,286	94	205.9	9.9	59
	Harrison	29,388,948	55	5,475,486	46		-	100.6	4.8	73
	Holmes	86,957,196	161	53,341,829	449	14,542,286	720	1,330.4	63.9	10
	Jefferson	20,014,176	37	3,355,943	28	622,200	31	96.2	4.6	74
	Monroe	29,581,392	55	6,005,371	51		-	105.4	5.1	72
	Tuscarawas	58,832,880	109	30,689,214	258	4,823,143	239	606.3	29.1	27
	Total Eastern	**384,888,000**	**715**	**136,136,471**	**1,145**	**37,152,771**	**1,840**	**3,700**	**178**	**6**
Northern	Erie	7,890,204	15	3,554,650	30	2,018,143	100	144.5	6.9	68
	Huron	18,584,592	35	9,537,943	80	8,837,571	438	552.4	26.5	30
	Lorain	21,746,172	40	12,717,257	107	4,713,857	233	380.8	18.3	43
	Lucas	2,639,232	5		-	6,105,429	302	307.3	14.8	52
	Ottawa	2,281,836	4		-	2,542,714	126	130.2	6.2	70
	Sandusky	13,993,428	26	4,415,714	37	5,180,143	257	319.7	15.3	50
	Seneca	22,268,520	41	4,106,614	35	16,407,429	813	888.5	42.6	17
	Wood	9,539,724	18		-	4,539,000	225	242.5	11.6	56
	Total Northern	**98,943,708**	**184**	**34,332,179**	**289**	**50,344,286**	**2,494**	**2,966**	**142**	**7**

Regions	Counties	Beef Cattle		Dairy Cattle		Swine		Total		
		Volatile Solids	Methane	Volatile Solids	Methane	Volatile Solids	Methane	Methane	Btu's	Rank
Northcentral	Ashland	54,626,604	101	27,995,629	235	9,231,000	457	794.1	38.1	18
	Crawford	18,282,180	34	4,901,443	41	24,990,000	1,238	1,312.9	63.0	11
	Hardin	20,014,176	37	3,894,660	33	25,492,714	1,263	1,332.6	64.0	9
	Knox	47,286,240	88	17,971,957	151	9,194,571	455	694.4	33.3	22
	Marion	15,615,456	29		-	14,476,714	717	746.0	35.8	21
	Morrow	20,976,396	39	6,226,157	52	7,912,286	392	483.2	23.2	36
	Richland	41,760,348	78	21,107,114	178	6,943,286	344	599.0	28.8	28
	Wayne	157,611,636	293	98,558,743	829	23,205,000	1,149	2,270.9	109.0	3
	Wyandot	11,244,228	21	3,753,357	32	23,889,857	1,183	1,235.7	59.3	12
	Total Northcentral	**387,417,264**	**719**	**184,409,060**	**1,551**	**145,335,429**	**7,198**	**9,469**	**455**	**2**
Northeastern	Ashtabula	38,186,388	71	23,756,543	200	1,238,571	61	332.1	15.9	48
	Columbiana	49,760,520	92	32,411,343	273	3,264,000	162	526.7	25.3	33
	Cuyahoga		-		-		-	-	-	-
	Geauga	15,780,408	29	9,582,100	81	642,600	32	141.7	6.8	69
	Lake		-		-		-	-	-	-
	Mahoning	23,835,564	44	14,262,757	120	1,734,000	86	250.1	12.0	55
	Medina	24,467,880	45	13,379,614	113	1,165,714	58	215.7	10.4	58
	Portage	18,502,116	34	8,434,014	71	961,714	48	152.9	7.3	65
	Stark	48,880,776	91	29,541,129	248	4,189,286	207	546.7	26.2	31
	Summit	2,859,168	5		-		-	5.3	0.3	86
	Trumbull	26,117,400	48	11,878,271	100	626,571	31	179.4	8.6	61
	Total Northeastern	**248,390,220**	**461**	**143,245,771**	**1,205**	**13,822,457**	**685**	**2,351**	**113**	**8**
Northwestern	Allen	14,598,252	27	3,245,550	27	18,556,714	919	973.5	46.7	15
	Defiance	19,354,368	36	5,431,329	46	5,486,143	272	353.3	17.0	45
	Fulton	36,399,408	68	4,857,286	41	33,652,714	1,667	1,775.2	85.2	4
	Hancock	8,247,600	15	3,797,514	32	14,906,571	738	785.6	37.7	19
	Henry	10,859,340	20	3,451,617	29	5,806,714	288	336.8	16.2	46
	Paulding	7,862,712	15	7,830,533	66	4,276,714	212	292.3	14.0	53
	Putnam	22,433,472	42	8,301,543	70	31,161,000	1,543	1,654.9	79.4	5
	Van Wert	7,340,364	14	4,172,850	35	7,599,000	376	425.1	20.4	41
	Williams	27,849,396	52	4,018,300	34	8,058,000	399	484.6	23.3	35
	Total Northwestern	**154,944,912**	**288**	**45,106,521**	**379**	**129,503,571**	**6,414**	**7,081**	**340**	**3**

Regions	Counties	Beef Cattle		Dairy Cattle		Swine		Total		
		Volatile Solids	Methane	Volatile Solids	Methane	Volatile Solids	Methane	Methane	Btu's	Rank
Southern	Adams	49,815,504	93	9,361,314	79	4,735,714	235	405.8	19.5	42
	Gallia	39,973,368	74	4,327,400	36	794,143	39	150.0	7.2	66
	Highland	44,262,120	82	4,327,400	36	4,240,286	210	328.6	15.8	49
	Jackson	22,983,312	43		-		-	42.7	2.0	80
	Lawrence	13,553,556	25		-		-	25.2	1.2	82
	Pike	16,687,644	31		-	731,000	36	67.2	3.2	75
	Ross	36,619,344	68	3,554,650	30	3,693,857	183	280.8	13.5	54
	Scioto	21,278,808	40		-		-	39.5	1.9	81
	Total Southern	**245,173,656**	**455**	**21,570,764**	**181**	**14,195,000**	**703**	**1,340**	**64**	**10**
Southeastern	Athens	18,969,480	35	3,532,571	30		-	64.9	3.1	77
	Hocking	7,807,728	14		-		-	14.5	0.7	83
	Meigs	19,436,844	36	3,576,729	30		-	66.2	3.2	76
	Morgan	29,883,804	55	3,444,257	29	2,907,000	144	228.4	11.0	57
	Muskingum	54,571,620	101	6,711,886	56	6,171,000	306	463.4	22.2	38
	Noble	24,247,944	45		-		-	45.0	2.2	79
	Perry	22,488,456	42	3,214,640	27	2,082,500	103	171.9	8.3	63
	Vinton	7,230,396	13		-		-	13.4	0.6	84
	Washington	43,959,708	82	9,008,057	76	3,052,714	151	308.6	14.8	51
	Total Southeastern	**228,595,980**	**424**	**29,488,140**	**248**	**14,213,214**	**704**	**1,376**	**66**	**9**
South western	Brown	33,567,732	62	4,857,286	41	1,537,286	76	179.3	8.6	62
	Butler	36,179,472	67	6,623,571	56	6,141,857	304	427.1	20.5	40
	Clermont	12,893,748	24		-	510,000	25	49.2	2.4	78
	Clinton	12,893,748	24		-	12,793,714	634	657.6	31.6	24
	Fayette	11,519,148	21		-	10,309,286	511	532.0	25.5	32
	Greene	17,374,944	32		-	10,892,143	539	571.7	27.4	29
	Hamilton	5,086,020	9		-		-	9.4	0.5	85
	Montgomery	10,501,944	20		-	6,338,571	314	333.4	16.0	47
	Preble	31,725,768	59	6,049,529	51	26,738,571	1,324	1,434.1	68.8	6
	Warren	15,587,964	29		-	2,506,286	124	153.1	7.3	64
	Total Southwestern	**187,330,488**	**348**	**17,530,386**	**147**	**77,767,714**	**3,852**	**4,347**	**209**	**4**

Regions	Counties	Beef Cattle		Dairy Cattle		Swine		Total		
		Volatile Solids	Methane	Volatile Solids	Methane	Volatile Solids	Methane	Methane	Btu's	Rank
Western	Auglaize	40,330,764	75	20,003,186	168	22,010,143	1,090	1,333.3	64.0	8
	Champaign	29,471,424	55	8,169,071	69	10,812,000	536	658.9	31.6	23
	Clark	25,485,084	47		-	6,433,286	319	366.0	17.6	44
	Darke	55,286,412	103	25,302,043	213	68,667,857	3,401	3,716.5	178.4	2
	Logan	28,316,760	53	11,171,757	94	10,076,143	499	645.6	31.0	25
	Mercer	83,520,696	155	51,398,914	432	69,491,143	3,442	4,029.2	193.4	1
	Miami	19,821,732	37	5,343,014	45	21,798,857	1,080	1,161.4	55.7	13
	Shelby	41,842,824	78	21,548,686	181	23,124,857	1,145	1,404.3	67.4	7
	Total Western	**324,075,696**	**602**	**142,936,671**	**1,202**	**232,414,286**	**11,511**	**13,315**	**639**	**1**
Ohio	**Total**	**2,422,622,532**	**4,499**	**790,699,879**	**6,650**	**781,478,586**	**38,706**	**49,855**	**2,393**	

6- Food processing wastes

Because no data currently exists regarding the amount and location of food processing wastes in the state of Ohio, the most desirable research option entails the collection of primary data from food processing companies using a survey instrument. For this study, a survey was developed and refined before attempts were made to administer the instrument via telephone and email; however, companies of all sizes throughout the state failed to respond, with the exception of one large food company which will be discussed below. The overall low response rate among companies resulted in the formulation of a two-phase approach for the biomass component of the research. This section outlines the two phases and illustrates the food waste biomass potential with a series of tables and GIS maps.

Phase One

The first phase, which this study primarily focuses on, involves the geo-referencing of all known food processing companies in Ohio by a variety of categories including the likely type of waste stream, the type of product the companies produce, the size of the company (in terms of employees), and the throughput (in volume) of the product produced. Estimates of the amount of food waste for each firm may be difficult to obtain without any previous studies that describe the relationship between food waste and variables like number of employees or type of end product produced. Therefore, information on throughput found in the Harris Ohio Industrial Directory (an annual compendium of all manufacturers in the state of Ohio) will be used as a naïve proxy for the amount of food waste produced.

Obviously, the major assumption being made in the first phase estimate of food waste volume is that the amount of food waste is directly related to the total throughput of the firm.

While this is a bold assumption, it should be noted that the goal of the first phase is not to display the exact amount of food waste at each location. Instead, phase one provides a base from which to demonstrate the potential size of the food processing waste biomass resource throughout the state of Ohio. It is hoped that the resulting GIS maps generated in this first phase combined with the maps and tables for other biomass resources will serve as tools to be used by the State or other organizations in their attempts to elicit responses to the actual food waste biomass survey.

The administration of the food processing waste survey makes up the second phase of this component of the biomass study. As was stated above, the information collected in phase one will be used to improve the response rate of any ensuing surveys. The dozens of companies who were contacted initially to participate in this study were not willing to help out, likely due to the fact that they had no relationship with the individuals conducting the study and possibly because the potential benefits to the companies could not be demonstrated. Graphical evidence of the food waste and other biomass potential is believed to improve the chances of participation by industries throughout the state, especially if a case can be made for economic benefits to the firms.

Phase Two

The recommended approach for completing phase two includes three main parts: education, administration, and interpretation. The education component is intended to convene food processing companies and demonstrate the food waste biomass energy potential and how a food waste-to-energy program in Ohio could enhance their operations (profit). As was discovered during this project, someone without a relationship with the companies will almost certainly not be able to gain the cooperation of companies in completing the survey. Therefore, careful consideration should be made regarding who contacts the companies and who presents the phase one information to the companies. Because issues of confidentiality may be of concern, it is crucial that companies be assured that any information they provide will be held strictly confidential. Furthermore, early meetings with several companies may facilitate greater cooperation, as managers will be able to see other companies involved with the project.

The administration component of phase two simply involves obtaining responses from the food processing companies. The recommended administration procedure for this study is a mixed-mode approach of telephone and email surveys. This recommendation stems from the difficult nature of the questions being asked in the survey. For instance, a manager may need to speak with other employees or review company records in order to determine the types and amount of food waste they generate every year. Some respondents may be able to answer such questions over the phone, but allowing them to answer questions at their convenience with an email survey should improve the response rate.

As with any survey, it will be important to follow up with companies who do not initially respond to the questionnaire. The recommended progression for administration of the survey begins with a pre-letter or phone call informing the company about the survey and why it is important. The next phase involves administering the telephone survey or sending the email survey for the company to complete. A reminder should then be made about a week later, asking those who did not respond to please do so as soon as possible. After two more weeks, a second contact should be made (including a re-delivery of the email survey or a second attempt at the telephone survey). This “four-wave” approach is consistent with Dillman’s (2000) techniques aimed at maximizing survey response rates.

Once the survey data is collected, information on food waste quantities, types, and locations should be geo-referenced in the same format as the original phase one GIS maps. It is hoped that the geo-referencing of the food processing waste data will aid the Ohio Department of Development and others in their continuing assessment of Ohio biomass for energy potential.

6.1 The Food Processing Waste Survey

The survey that was developed (see a completed survey in Appendix A-2) was intended for easy administration over the phone or via email (though postal mail could also be utilized). While the length of the survey is fairly short, it is anticipated that many companies may have trouble answering some of the questions or may be hesitant to disclose specific information on their operations (such as the composition of their waste streams). This concern was supported by our low response rate in the survey pre-test phase of the study.

However, positive feedback (and a completed survey) was obtained from Pamela Carter of Frito Lay, a large food processing firm in Ohio. Not only did Ms. Carter complete the survey, but she did so with very specific responses to questions involving waste composition, amount of food waste per year to the nearest pound, and the amount of money that specific wastes were sold for to the nearest penny per unit. Ms. Carter also expressed that Frito Lay would be extremely supportive of a food waste-to-energy program in Ohio if the state would provide the company payments for their waste. That a large, well-known firm such as Frito Lay is willing to volunteer such specific data on their waste streams is an encouraging sign for this study. It is recommended that Ms. Carter be contacted again if a decision is made to go ahead with phase two of the study.

6.2 Food Waste Potential

As was stated above, the Harris Ohio Industrial Directory was used to collect information on all known food processing companies in Ohio. Variables in the directory include estimated annual sales, number of employees, and size of the plant (in square feet). Information is also provided on the type of product the company produces, allowing for an analysis of the quantity and location of various types of food waste throughout the state. For the quantity of food waste produced, estimated annual sales was assumed to be a good proxy in that one would assume that the more product sold translates into more waste produced (though it could be argued that larger plants may be more efficient due to economies of scale). The number of employees and the size of the plant were used as secondary proxies of food waste quantity (again, assuming more employees and a larger plant equate to more food waste produced).

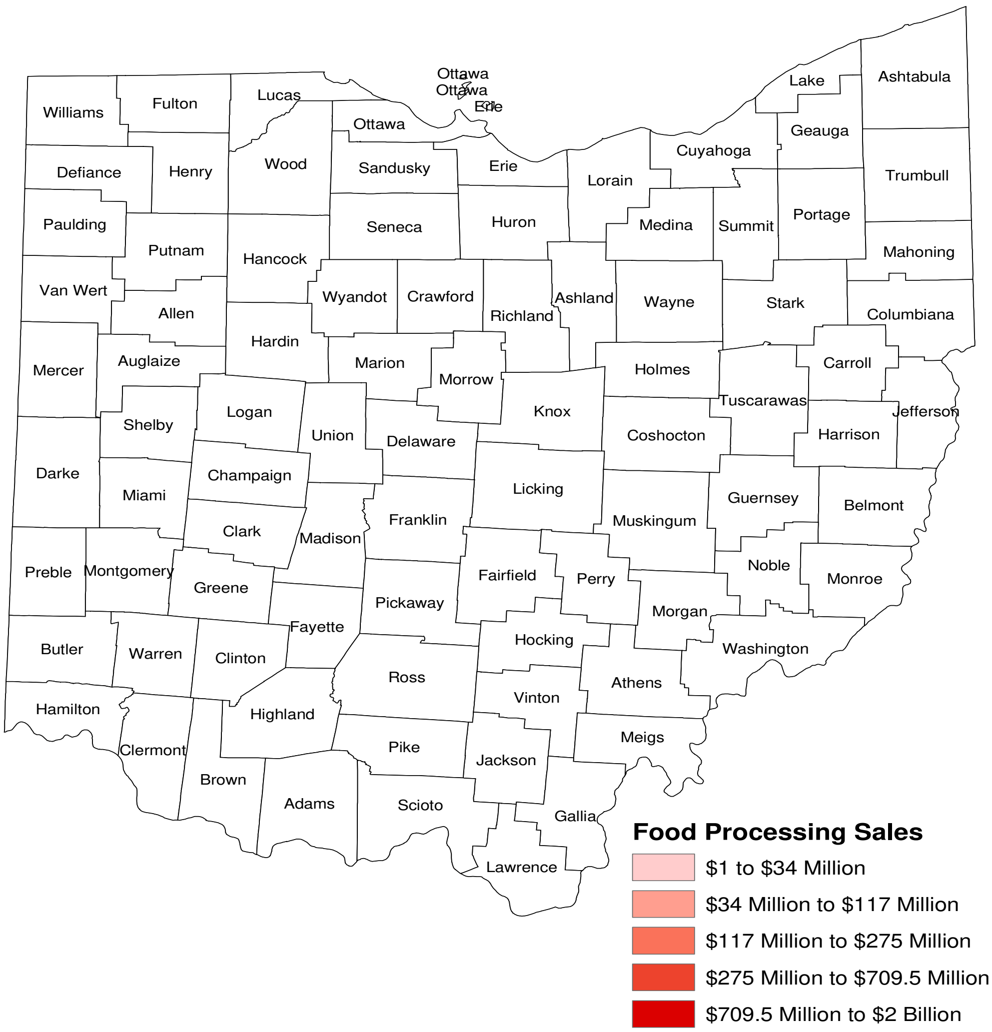
Below are tables highlighting the top ten counties in Ohio with regard to the estimated food processing company sales, the number of food processing company employees, and the total size of food processing plants, along with GIS maps of the data for all counties in the state.

Table 6.1: Estimated Minimum Sales of Food processing Companies by County in Ohio

Rank	County	Estimated Minimum Sales
1	Hamilton	$2,002,500,000
2	Franklin	$1,769,500,000
3	Cuyahoga	$709,500,000
4	Henry	$530,000,000
5	Summit	$372,500,000
6	Stark	$362,000,000
7	Lucas	$327,000,000
8	Montgomery	$320,500,000
9	Butler	$275,000,000
10	Wood	$264,000,000
	State Total	$11,843,500,000
	Top Ten Percent of State Total	45.5%

Map 6.1:

Estimated Minimum Food Processing Sales by County, 2003



In Table 6.1, several things are evident. First, it is no surprise that the top three counties in sales are the three most populated counties in Ohio. Second, food processing wastes, if they correlate with sales, are scattered throughout the state (evident in Map 6.1), with the greatest quantities found in the more urban areas. The only part of the state with what seems like a small amount of food processing waste is the southeastern region. Third, a large percent of the total food processing waste (again, assuming that sales are a good estimate of the amount of waste) is located in a handful of counties. In Table 6.1, it is shown that almost half of the food processing sales are accounted for by 10 counties. In fact, Hamilton and Franklin counties account for about one quarter of the state's food processing sales.

Tables 6.2 and 6.3 below, which feature the amount of food processing jobs and the size of the food processing plants, appear to support the relative contributions of food processing throughput by counties in Ohio. Most counties appearing in the top ten in Tables 6.2 and 6.3 also appear in the top ten in sales, and the top three counties in all three tables include Cuyahoga, Franklin, and Hamilton counties.

Table 6.2: Food Processing Company Employees by County

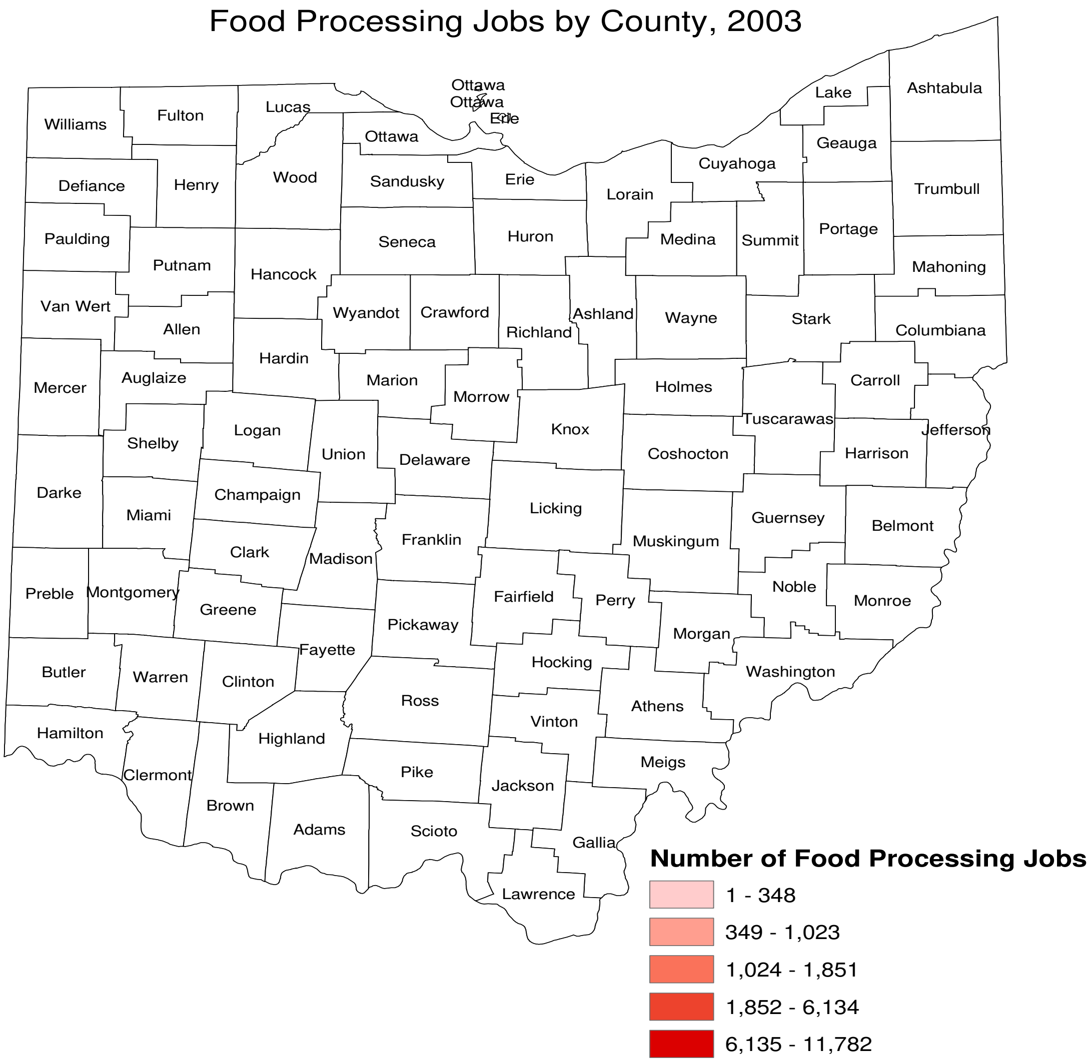
Rank	County	Employees
1	Hamilton	11,782
2	Franklin	10,248
3	Cuyahoga	6,134
4	Stark	3,497
5	Jackson	2,790
6	Summit	2,677
7	Wayne	1,851
8	Hancock	1,772
9	Butler	1,765
10	Henry	1,651
	State Total	74,401
	Top Ten Percent of State Total	46.3%

Table 6.3: Square Footage of Food Processing Plants in Ohio by County

Rank	County	Total Square Feet of Food Processing Plants
1	Franklin	3,576,625
2	Cuyahoga	1,834,150
3	Hamilton	1,820,400
4	Miami	1,188,400
5	Marion	1,187,300
6	Stark	1,100,484
7	Lucas	731,160
8	Summit	624,100
9	Wayne	591,600
10	Wood	544,472
	State Total	22,746,103
	Top Ten Percent of State Total	42.2%

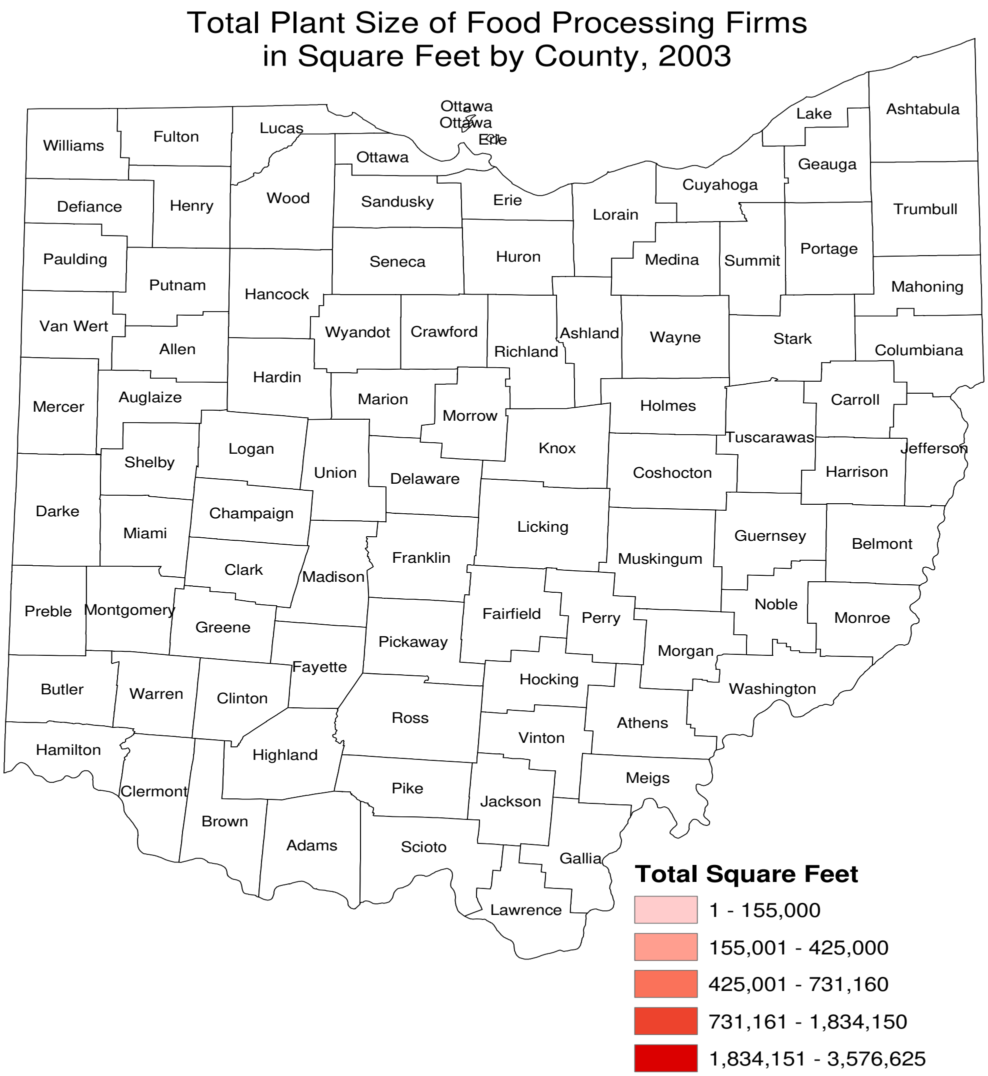
Interestingly, the data also lend some support to the original hypothesis that a large percentage of the total food processing waste in Ohio might be produced in concentrated areas. Using any of the three variables (sales, jobs, or plant size) results in the finding that almost half of the food processing products are produced by firms in only 10 counties (of 88 total counties). Below are the graphical representations of the food processing job and plant size data.

Map 6.2:



Food Processing Jobs by County, 2003
Williams
Fulton
Lucas
Ottawa
Ottawa
Erie
Ottawa
Lake
Ashtabula
Geauga
Cuyahoga
Defiance
Henry
Wood
Sandusky
Erie
Lorain
Trumbull
Paulding
Putnam
Seneca
Huron
Medina
Summit
Portage
Hancock
Mahoning
Van Wert
Allen
Wyandot
Crawford
Richland
Ashland
Wayne
Stark
Columbiana
Mercer
Auglaize
Hardin
Marion
Morrow
Holmes
Carroll
Tuscarawas
Logan
Knox
Jefferson
Shelby
Union
Delaware
Coshocton
Harrison
Darke
Champaign
Licking
Miami
Guernsey
Belmont
Franklin
Muskingum
Clark
Madison
Noble
Preble
Montgomery
Fairfield
Perry
Monroe
Greene
Pickaway
Morgan
Fayette
Hocking
Butler
Warren
Clinton
Washington
Ross
Athens
Vinton
Hamilton
Highland
Meigs
Pike
Clermont
Jackson
Brown
Adams
Scioto
Gallia
Lawrence
Number of Food Processing Jobs
1 - 348
349 - 1,023
1,024 - 1,851
1,852 - 6,134
6,135 - 11,782

Map 6.3:

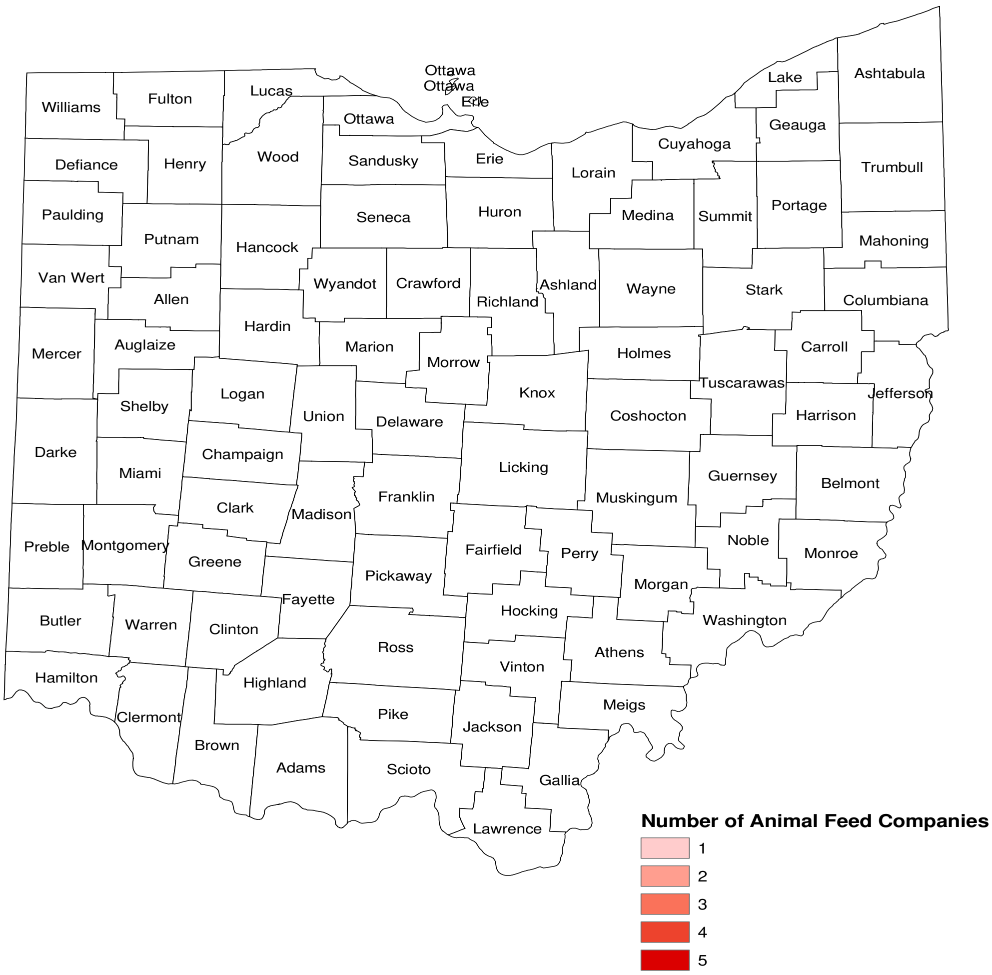


While the above tables and maps show an overall picture of the potential food processing waste biomass resource in Ohio, it is important to look at the distribution of the different types of food processing waste. To do this, the food processing data set was sorted by the type of product made by the firm. The information for the type of project is made available in the Harris directory using standardized SIC codes. All firms that produced meat related products, for instance, were grouped together into a meat processing category. Likewise, fruit and vegetable processing companies were grouped together. Sorting the dataset in this way resulted in about 13 major types of food processing companies. After the companies were grouped, the data was sorted again by county so that the information could be displayed in GIS maps.

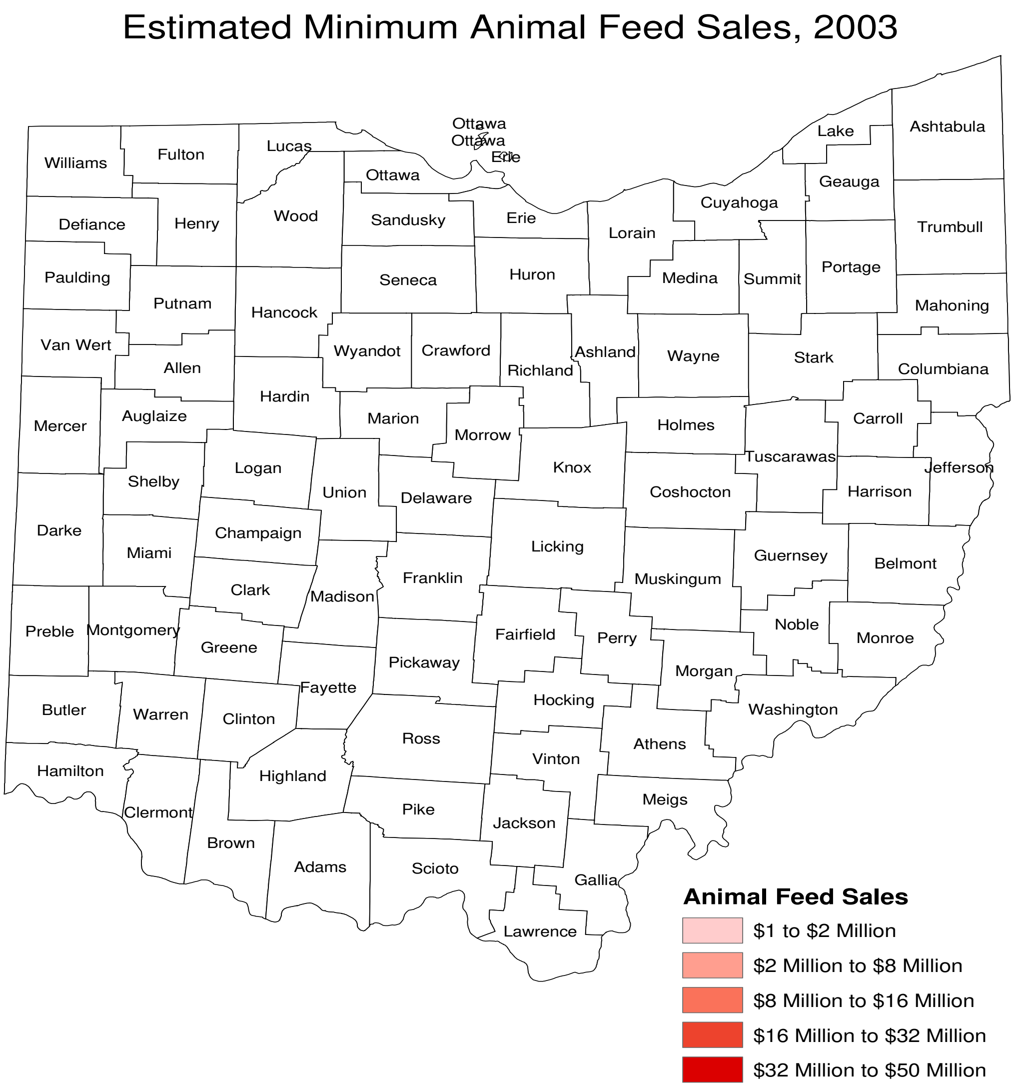
The followings are the GIS maps for the food processing output types that had the most firms throughout the state. These include animal feed processing firms, bread and bakery processing firms, dairy processing firms, fruit and vegetable processing firms, grain firms, and meat processing firms. The distribution of each type through the state is illustrated with two maps: one showing the number of firms and one showing the amount of sales (See Maps 6.4 and 6.5). The GIS maps for the remaining major food processing firm types can be found in Appendix A-3.

Map 6.4:

Number of Animal Feed Firms, 2003



Map 6.5:


Estimated Minimum Animal Feed Sales, 2003
Williams
Fulton
Lucas
Ottawa
Ottawa
Erie
Lake
Ashtabula
Geauga
Cuyahoga
Defiance
Henry
Wood
Sandusky
Erie
Lorain
Trumbull
Paulding
Putnam
Hancock
Seneca
Huron
Medina
Summit
Portage
Mahoning
Van Wert
Allen
Wyandot
Crawford
Richland
Ashland
Wayne
Stark
Columbiana
Mercer
Auglaize
Hardin
Marion
Morrow
Holmes
Carroll
Shelby
Logan
Union
Delaware
Knox
Coshocton
Tuscarawas
Harrison
Jefferson
Darke
Miami
Champaign
Licking
Guernsey
Belmont
Clark
Madison
Franklin
Muskingum
Preble
Montgomery
Greene
Fairfield
Perry
Noble
Monroe
Pickaway
Morgan
Butler
Warren
Clinton
Fayette
Hocking
Washington
Ross
Athens
Hamilton
Highland
Vinton
Meigs
Clermont
Pike
Jackson
Brown
Adams
Scioto
Gallia
Lawrence
Animal Feed Sales
$1 to $2 Million
$2 Million to $8 Million
$8 Million to $16 Million
$16 Million to $32 Million
$32 Million to $50 Million

6.3 Animal Feed Processing Firms

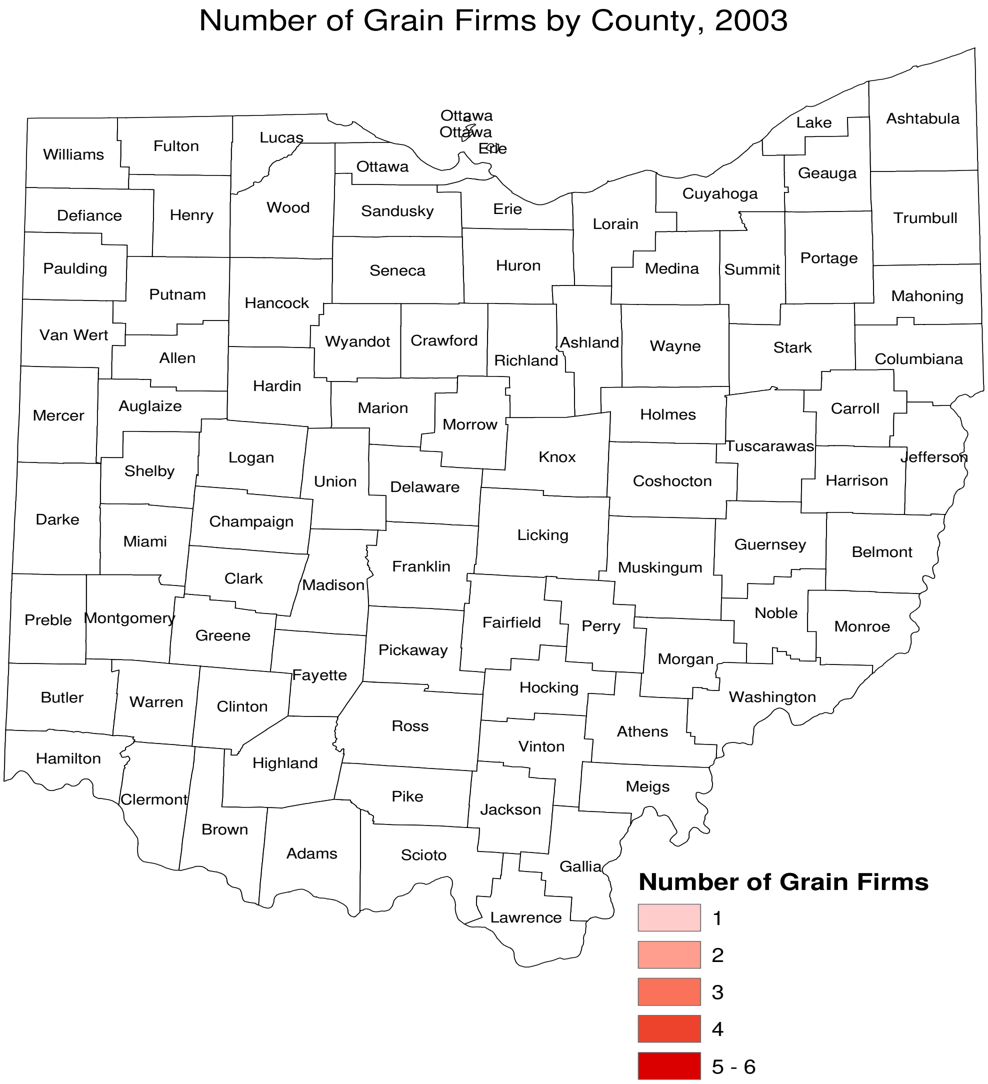
The animal feed processing firms have perhaps the most widespread geographical dispersion of any of the major food types. As with total food processing companies, the only location where animal feed processing firms are hard to find is the southeastern portion of the state.

The animal feed processing firm sales hint that there may be a greater amount of waste to be found in two locations in Ohio: in a belt stretching west to east from Mercer to Columbiana Counties and in the three-county pocket of Clinton, Fayette, and Pickaway Counties in the southwester section of the state.

6.4 Grain Processing Firms

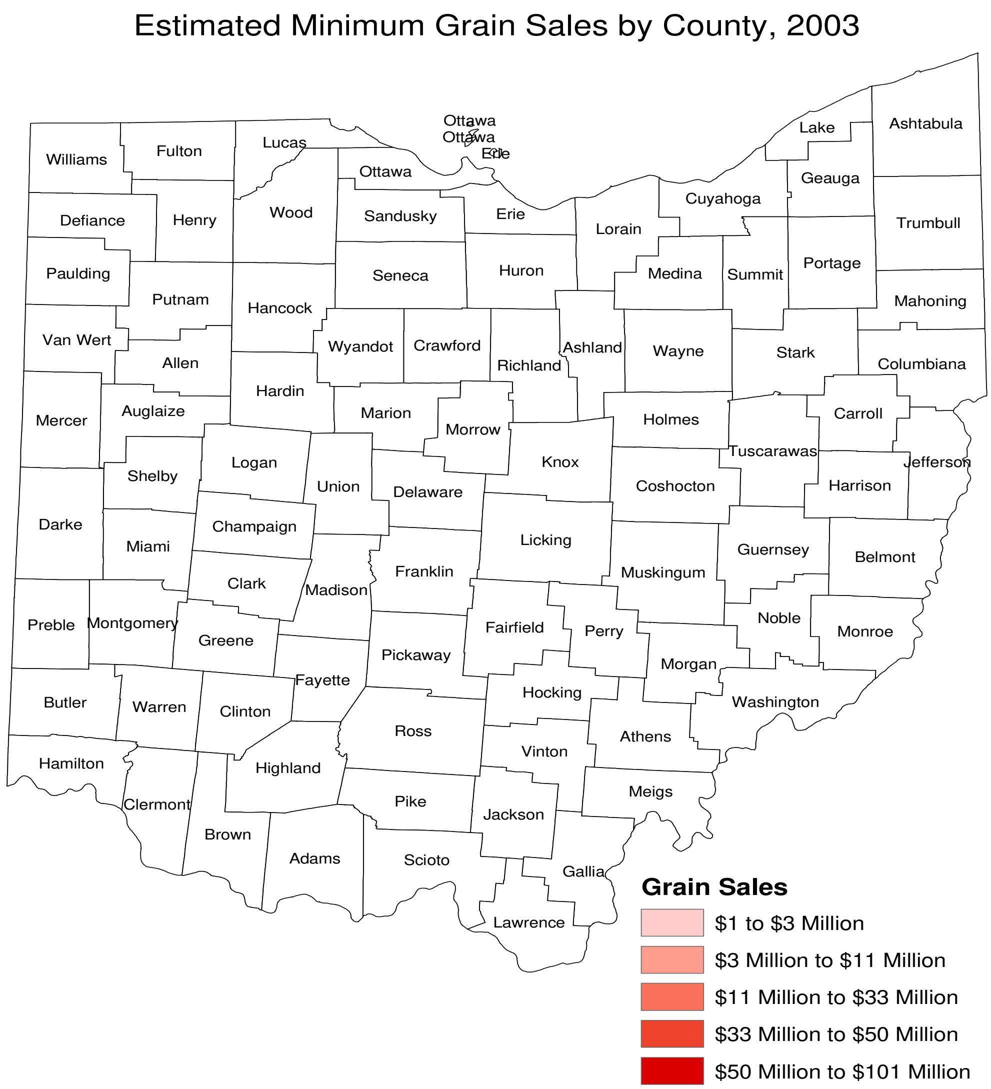
Another food processing type that enjoys widespread availability is grain. As shown in Map 6 below, grain producing firms are found in all regions of Ohio, even in the southeast; however, a concentrated number of firms are found in the northwest. Unlike the animal feed processing firms, sales figures for grain firms indicate that food waste volume from grain is as evenly distributed as the firms themselves (see Map 6.7 below).

Map 6.6:



Number of Grain Firms by County, 2003
Williams
Fulton
Lucas
Ottawa
Ottawa
Erie
Lake
Ashtabula
Defiance
Henry
Wood
Sandusky
Erie
Lorain
Cuyahoga
Geauga
Trumbull
Paulding
Putnam
Hancock
Seneca
Huron
Medina
Summit
Portage
Mahoning
Van Wert
Allen
Wyandot
Crawford
Richland
Ashland
Wayne
Stark
Columbiana
Mercer
Auglaize
Hardin
Marion
Morrow
Holmes
Carroll
Tuscarawas
Jefferson
Shelby
Logan
Union
Delaware
Knox
Coshocton
Harrison
Darke
Miami
Champaign
Licking
Guernsey
Belmont
Clark
Madison
Franklin
Muskingum
Preble
Montgomery
Greene
Fairfield
Perry
Noble
Monroe
Pickaway
Morgan
Fayette
Butler
Warren
Clinton
Hocking
Washington
Ross
Athens
Hamilton
Highland
Vinton
Meigs
Clermont
Pike
Jackson
Brown
Adams
Scioto
Gallia
Lawrence
Number of Grain Firms
1
2
3
4
5 - 6

Map 6.7:

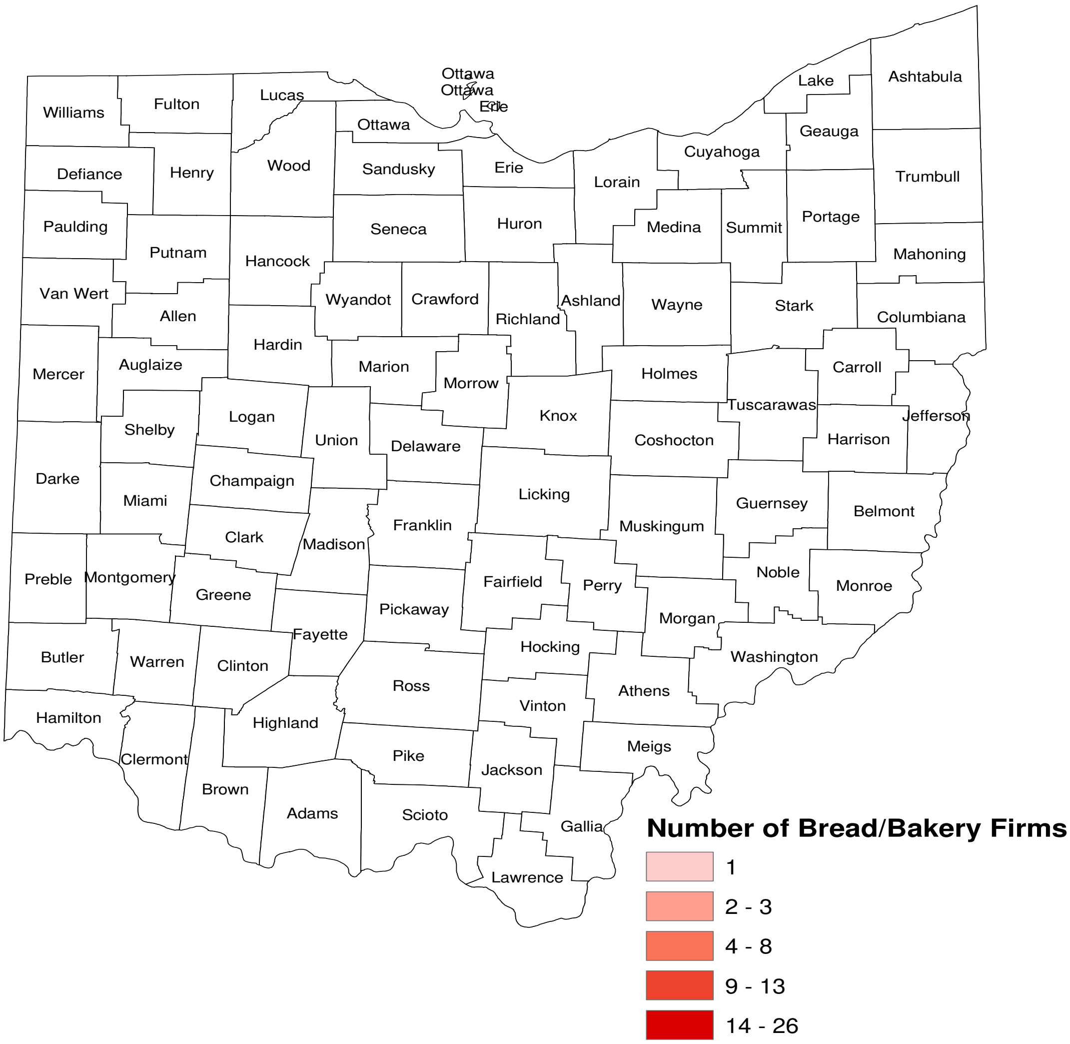


6.5 Bread and Bakery Producing Firms

The next food type analyzed in the GIS maps below (Maps 6.8 and 6.9), bread and bakery goods, likely shares compositional similarities with the animal feed and grain firms. And like the previously discussed food types, the bread and bakery goods firms can be found in large numbers throughout Ohio. As far as the number of firms is concerned, the bread and bakery companies are located in all regions of the state, with concentrations located in and around Ohio's three largest counties: Hamilton, Franklin, and Cuyahoga. The potential size of the food waste resource offered by bread and bakery firms is distributed in much the same way, with the largest amount of bread and bakery sales found in Hamilton, Franklin, Cuyahoga, and Huron Counties.

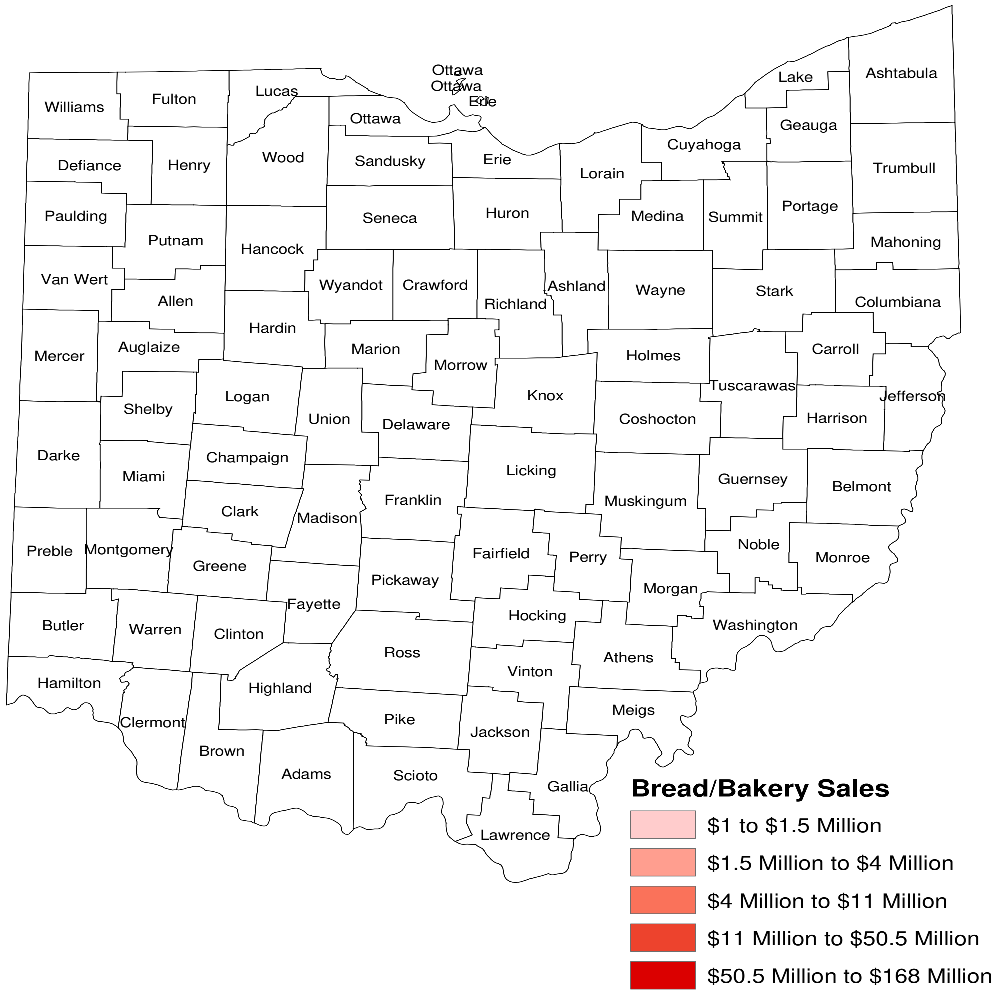
Map 6.8:

Number of Bread/Bakery Firms by County, 2003



Map 6.9:

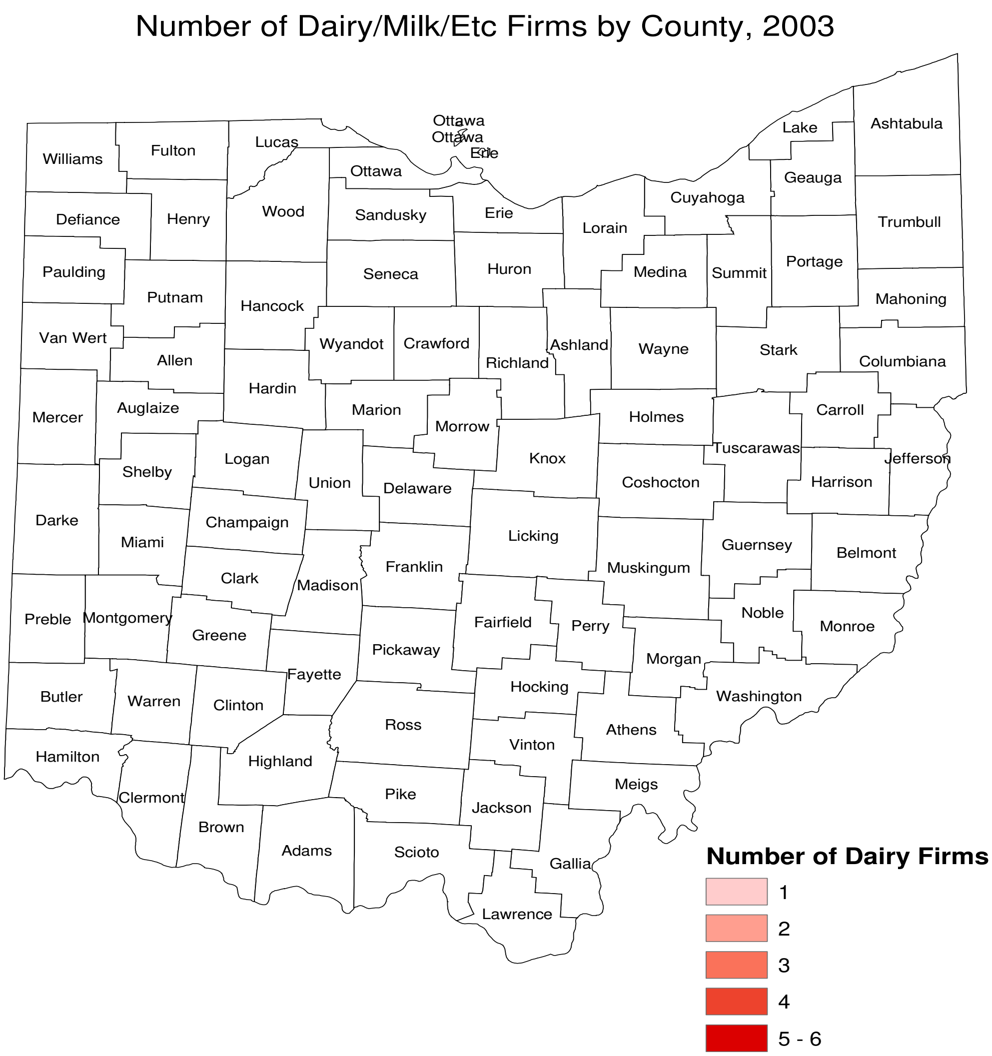
Estimated Minimum Bread/Bakery Sales by County, 2003



6.6 Dairy and Milk Processing Firms

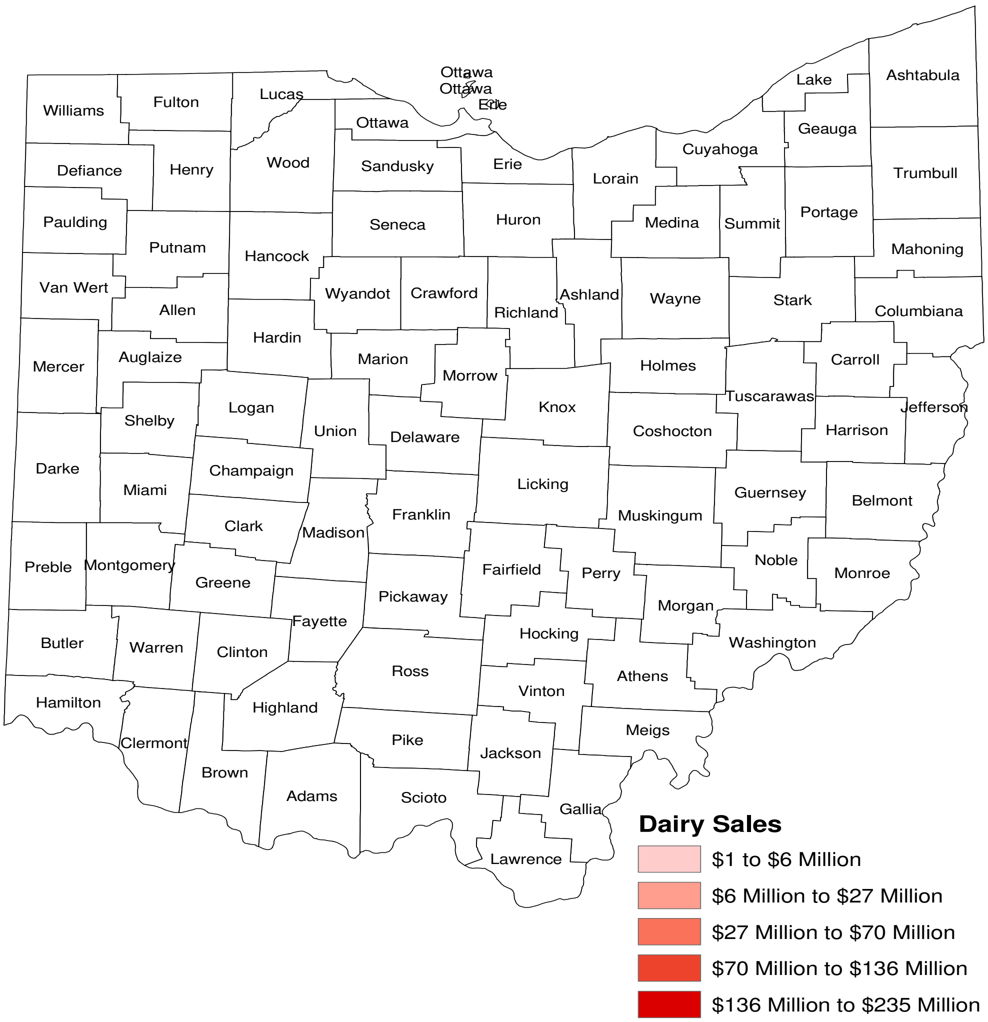
Dairy processing firms are less widespread throughout the state, but can be found in large concentrations in several areas of Ohio (see Map 6.10). The entire northeast region is a magnet for dairy firms, with Summit, Stark, and Tuscarawas Counties containing the greatest number of companies. Other large concentrations of firms include Lucas County in the northwest and Hamilton County in the southwest. In Map 6.11, it is evident that the northeast holds the most promise for large volumes of food waste from dairy and milk processing firms, though pockets of high volume may exist in Hamilton and Lucas Counties. It also appears as if a higher volume of waste could potentially exist in a band running northeast from Greene County, through Franklin and Licking Counties, to Trumbull County. This matches up well with major highways in the state.

Map 6.10:



Map 6.11:

Estimated Minimum Dairy/Milk/Etc Sales by County, 2003

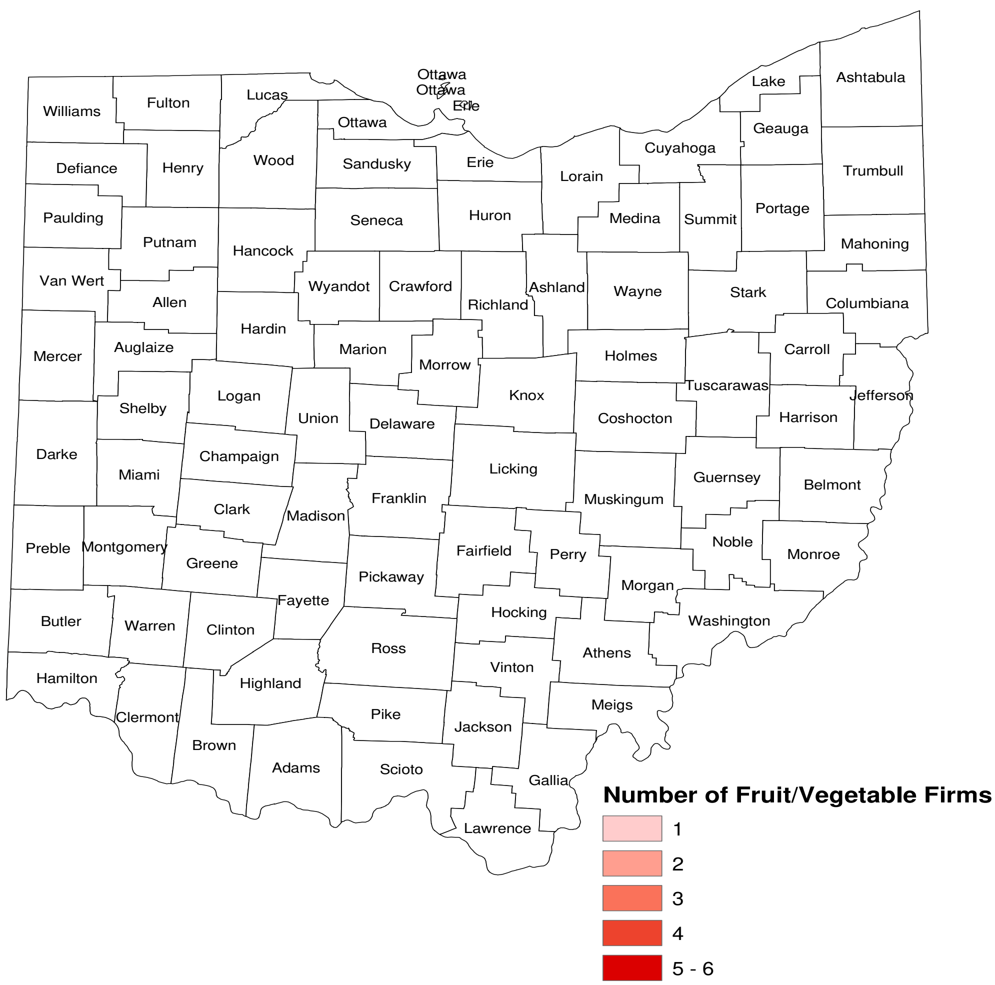


6.7 Fruit and Vegetable Processing Firms

The fruit and vegetable processing firms can also be found predominantly in the northeast section of the state, however large concentrations also exist in Franklin and Hamilton Counties, and in and around Sandusky County. Interestingly, the potential waste resource (using sales as the proxy for waste) is dispersed in five concentrated areas: Jackson County in the southern part of the state, Hamilton County in the southwest, Franklin and Coshocton Counties in the center of the state, and the Sandusky County region in the northern part of the state. The northeastern portion of the state is home to a less concentrated but more widespread potential waste resource. See Maps 6.12 and 6.13 below.

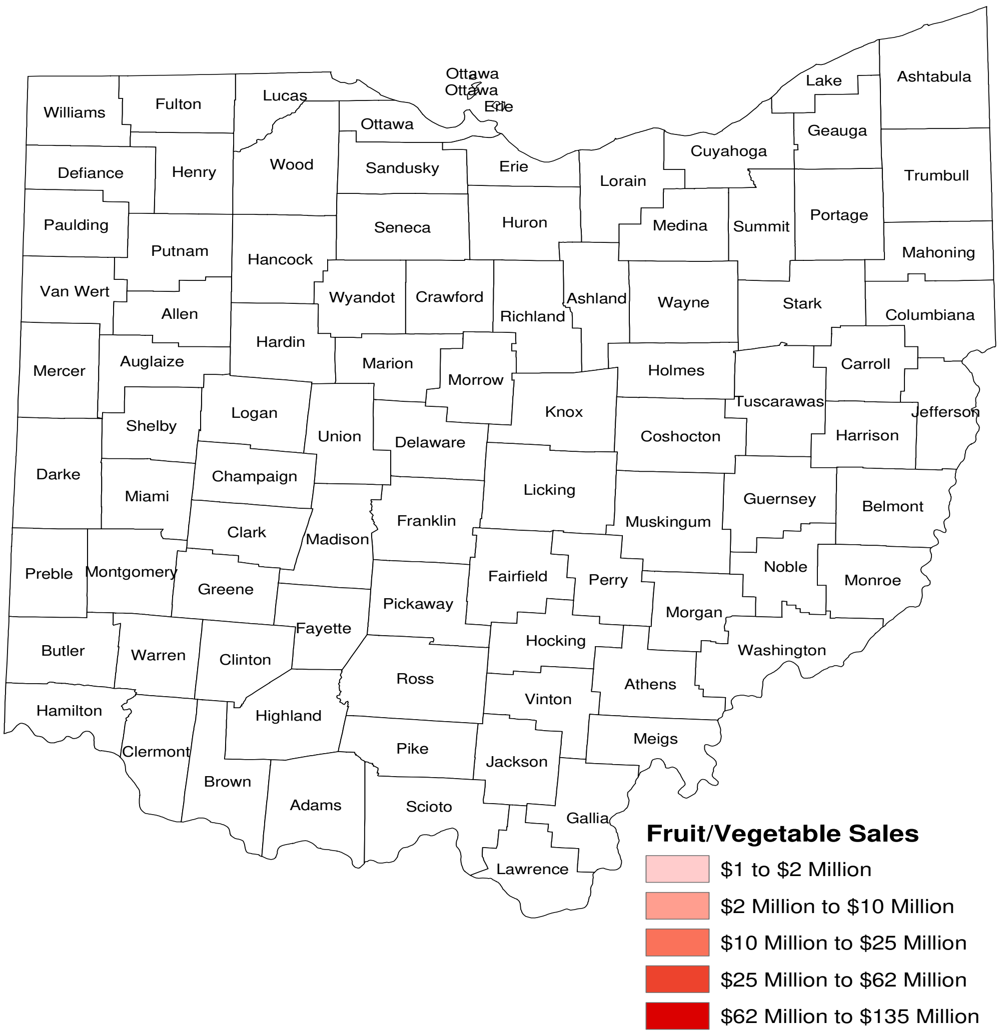
Map 6.12

Number of Fruit/Vegetable Firms by County, 2003



Map 6.13

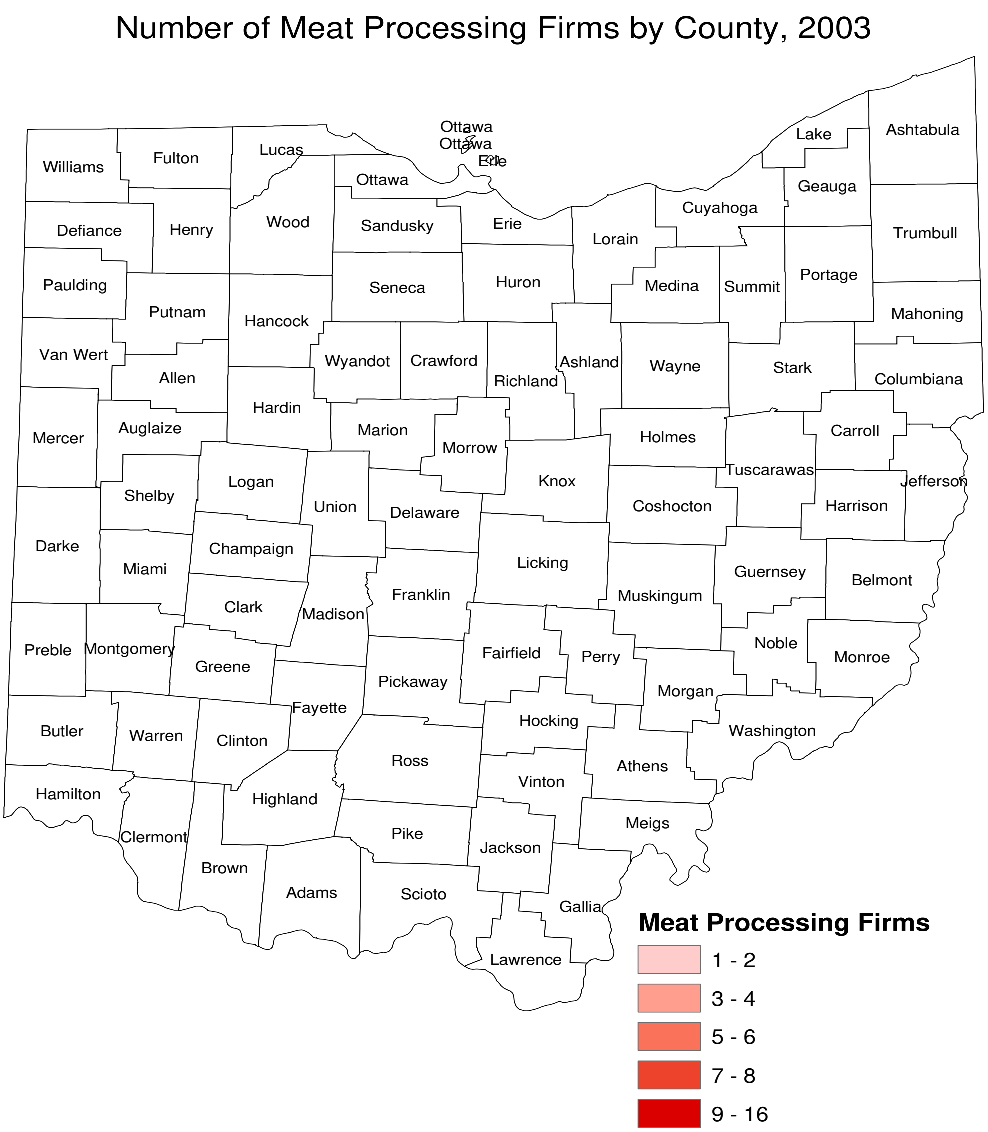
Estimated Minimum Fruit/Vegetable Sales by County, 2003



6.8 Meat Processing Firms

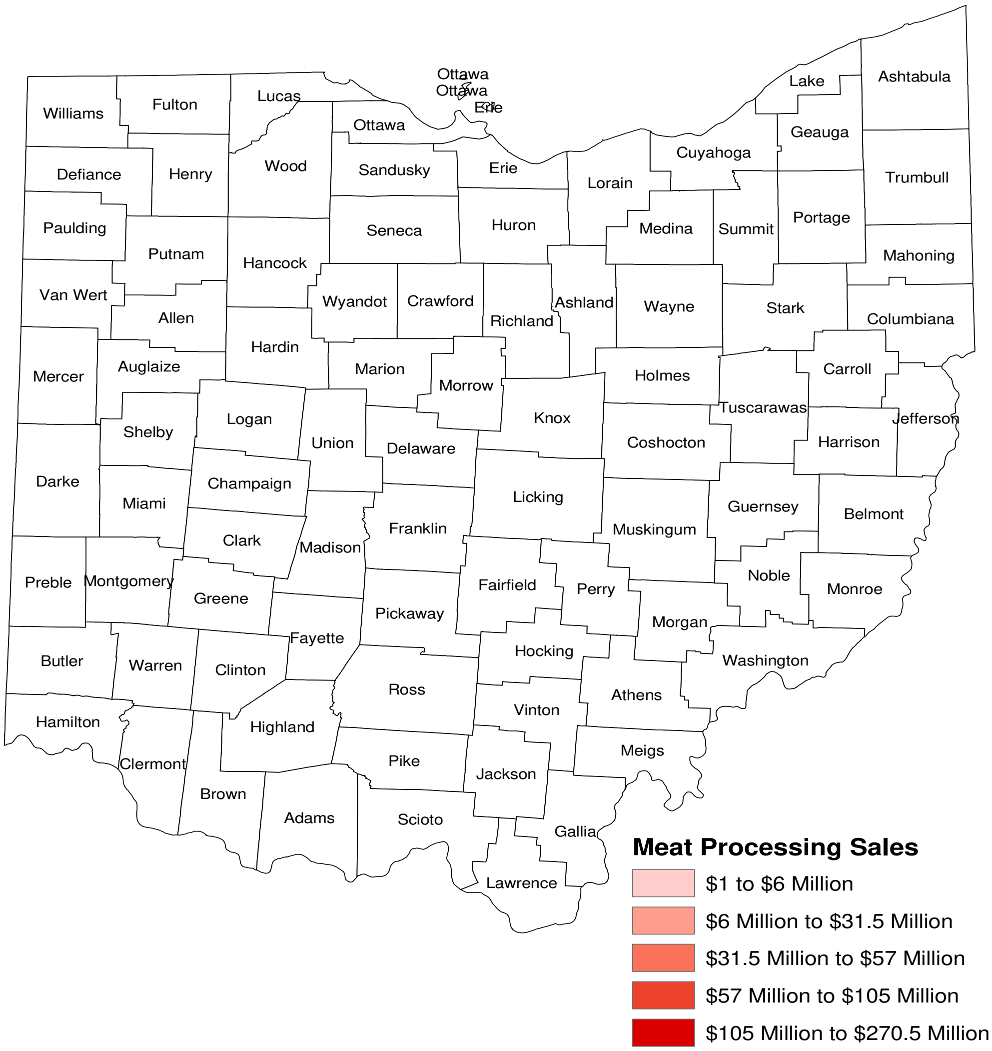
The final major food processing type illustrated in Maps 6.14 and 6.15 below is meat processing. Except for the southeastern section of the state, meat processing firms are found in a majority of the counties in Ohio, with higher concentrations in the northeast and central regions. The counties with the greatest number of meat processing firms include Cuyahoga, Franklin, Hamilton, Wayne, and Stark Counties. Map 6.15 shows promise for meat processing waste, with potentially large concentrations located in the northeastern counties, the Sandusky region, and the southwestern counties. The greatest amount of waste (using sales as a proxy) is likely found in Hamilton County.

Map 6.14



Map 6.15

Estimated Minimum Meat Processing Sales by County, 2003



6.9 Other Food Processing Firms

The remaining GIS maps for other food processing firms in the state of Ohio are located in Appendix A-3. It is hoped that all maps included in this study will guide the Ohio Department of Development in targeting efforts to gain more information about the food waste biomass resource in the state.

7. Biomass summary

In summary, the results of this biomass inventory indicates that Ohio has biomass energy potential of 289.8 trillions Btu's which is equivalent to 84.9 billions kWh annually, given that 3,413 Btu's are needed per kWh. This potential would appear to be even higher were detailed data on food processing wastes available as Ohio ranks fourth among the 50 states in value added food processing production - after California, Illinois, and Texas - according to the US Bureau of Economic Analysis. Considering the other biomass sources, regional and spatial distribution, the findings of this assessment are summarized in Figures 7.1, 7.2 and 7.3; Map 7.1 and Table 7.1. Looking at Figure 7.1 signifies that municipal solid wastes constitutes the largest biomass energy potential for Ohio, far exceeding the other biomass sources and providing 68% of the annual potential. Crop residues and wood biomass represent 19% and 12% respectively. Livestock manure methane potentially constitutes an extremely limited source of biomass energy, providing only 1%. MSW, also has the advantage of already being transported to central collection/disposal point.

Figure 7.2 shows the annual energy potential distribution by source and geographic unit for non-food processing biomass. The Northeastern, Southwestern and Southern regions hold the substantial fraction of the total municipal solid wastes, accounting for 28.49%, 17.20% and 15.32% respectively. The Northwestern and Western regions have the largest concentrations of crop residues, with 22.19% and 18.95%. The major wood biomass potential is found in the Northeastern, Southern and Southwestern regions, with 23.15%, 18.37%, and 12.56% respectively. Although of limited potential, methane energy is concentrated in the Southern, Northcentral and Northwestern regions at 26.71%, 18.99% and 14.20% respectively.

Combining all sources (except food processing facilities), Figure 7.3 points out that the Northeastern, Southwestern, Southern and Northern regions maintain the highest annual biomass energy potential, representing 22.82%, 15.47%, 13.31% and 11.95% respectively. Finally, Map 7.1 displays spatially the county distribution of the total annual biomass energy potential presented in Table 7.1.

As indicated above, the summary does not include food processing wastes due to data limitation. However, since most of the sales generated by the Ohio food processors are concentrated in Hamilton, Franklin, Cuyahoga, and stark counties, these counties can be predicted to produce the largest amount of food processing wastes.

Figure 7.1: Potential Energy Sources in Ohio (Billions Btu's and Percentage)

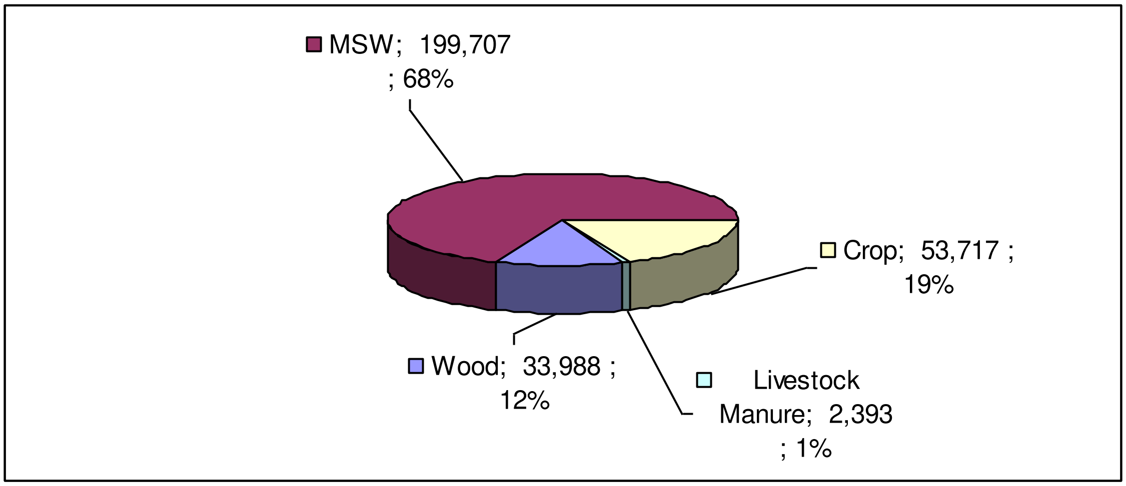


Figure 7.2: Potential Energy Source by Geographical Unit

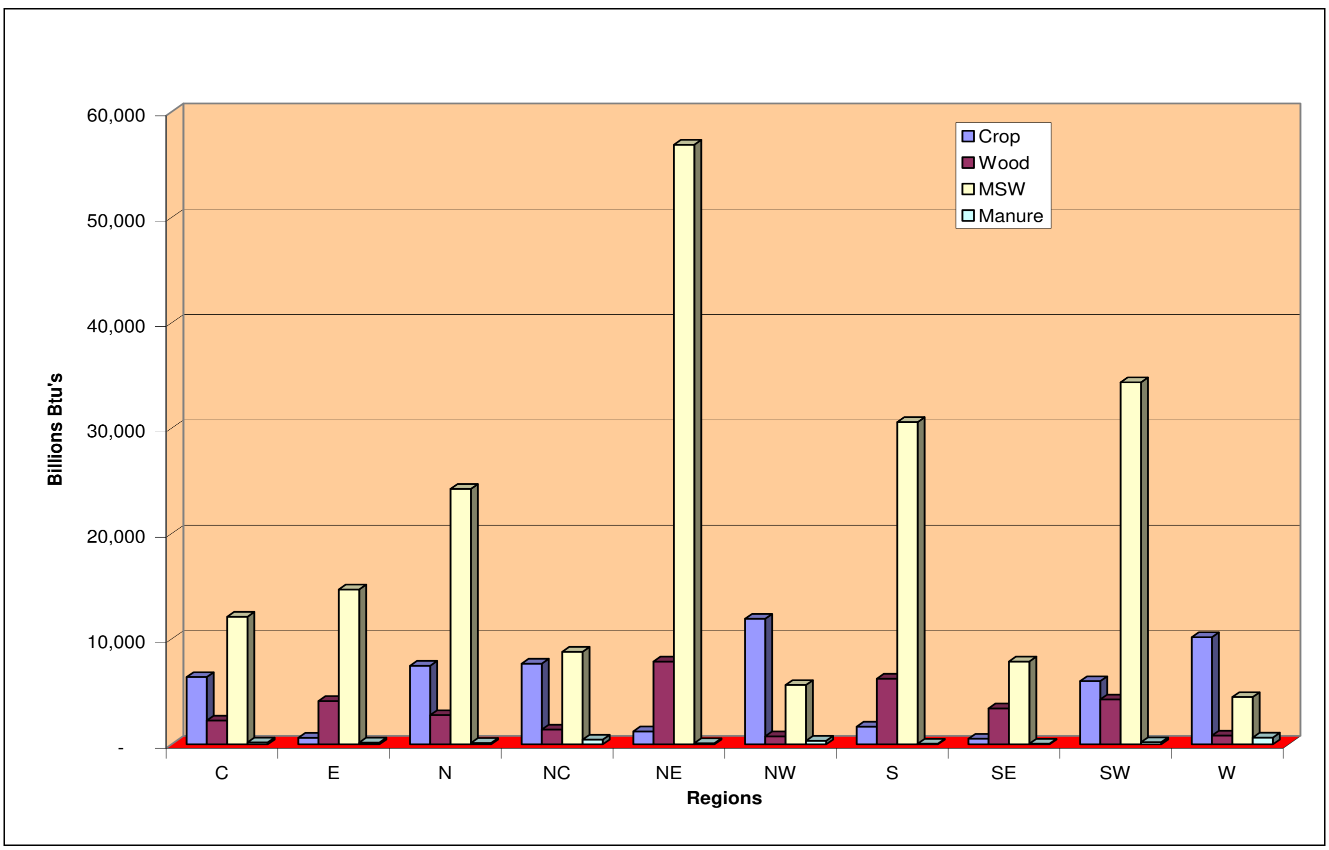
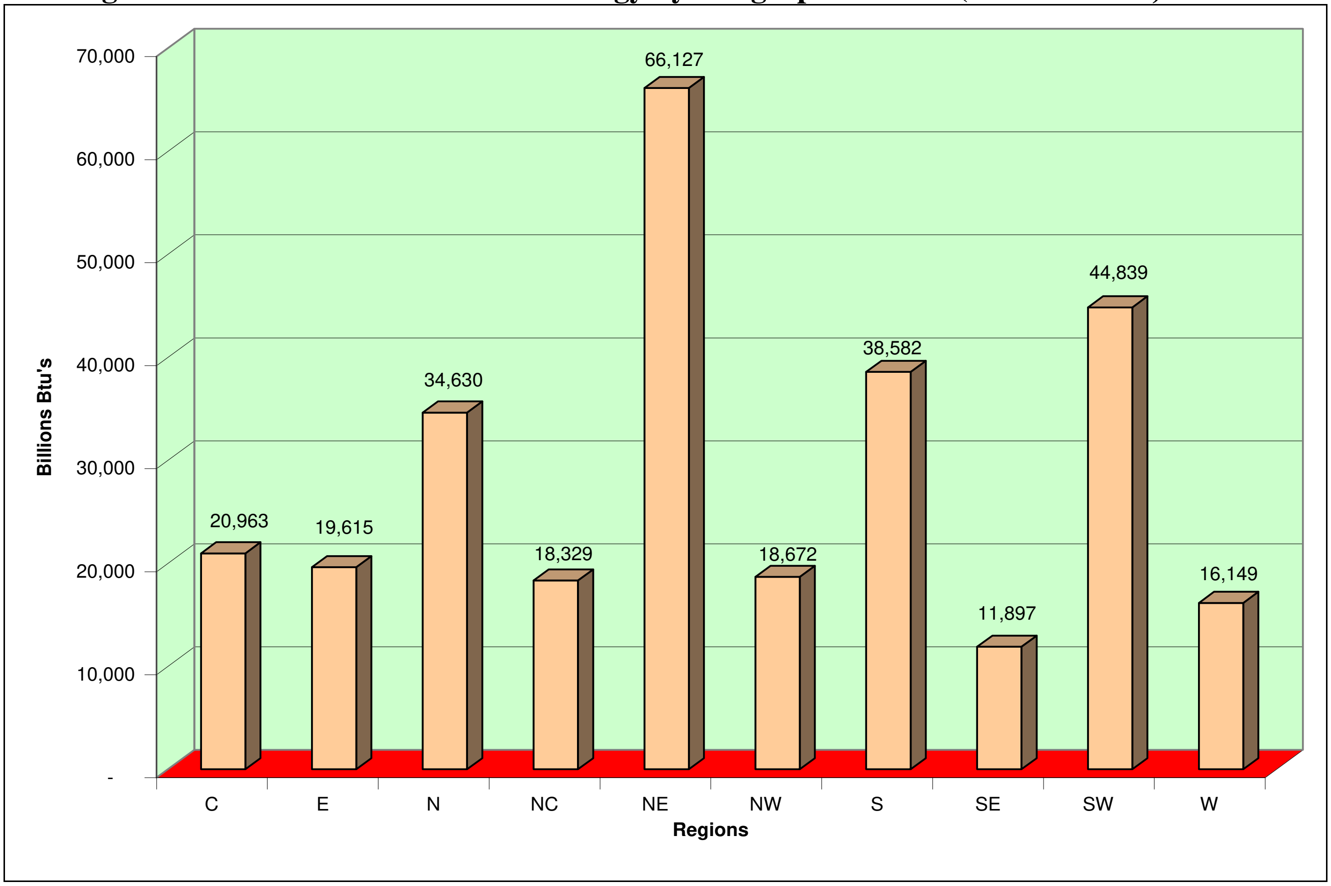


Figure 7.3: Ohio Annual Potential Energy by Geographical Unit (Billions Btu's)



Map 7.1: Potential Energy Distribution among Ohio Counties (in Billions)

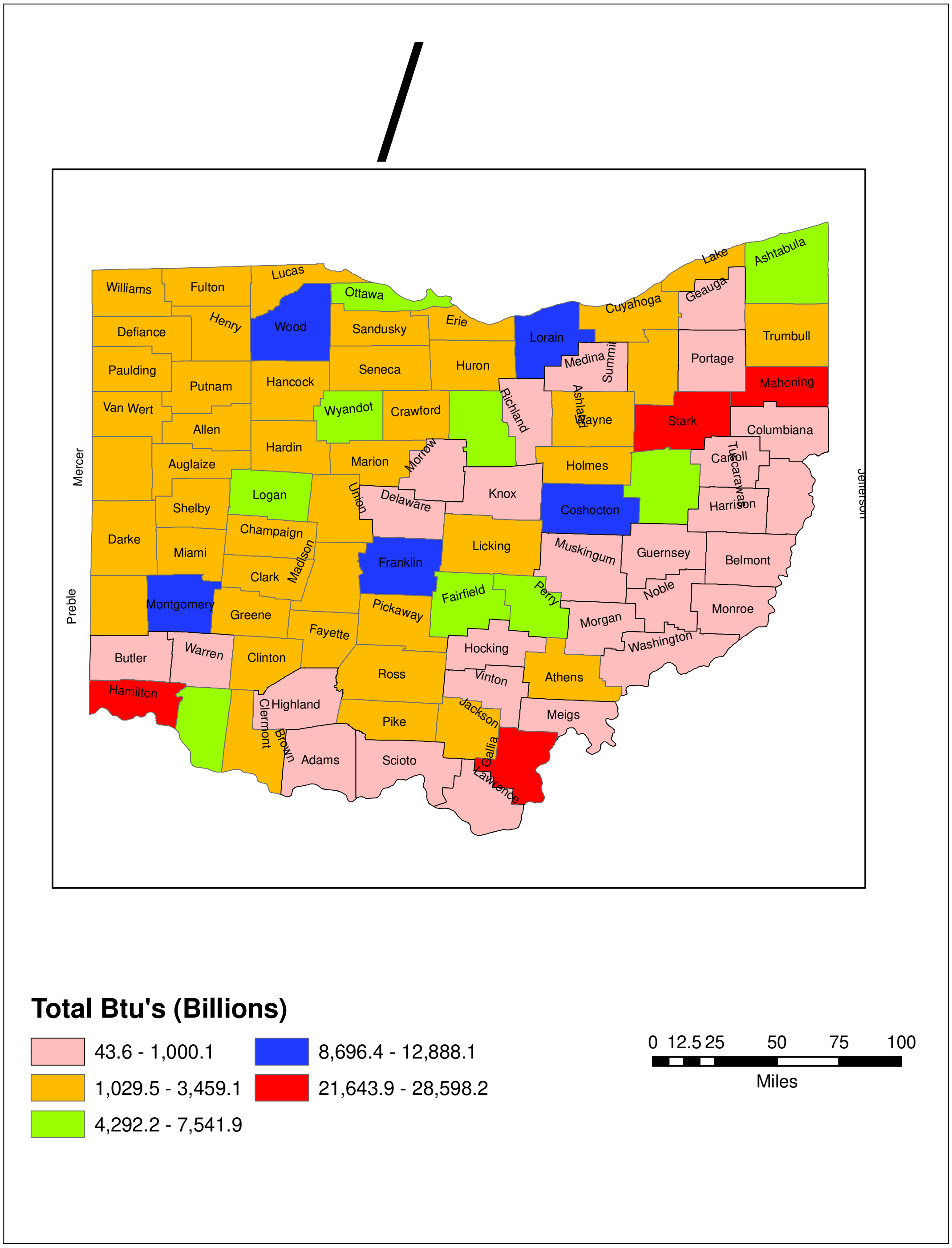


Table 7.1: Summary of Available Energy in Ohio Counties (in Billions Btu's)

Regions	Counties	Crop Residues	Wood Wastes	MSW [1]	Livestock Manure	Total Btu's	% of Total	Rank
Central	Delaware	671.4	100.2	-	21.2	792.8	0.27	63
	Fairfield	909.6	360.7	2,997.9	23.9	4,292.2	1.48	18
	Franklin	282.0	1,241.4	8,844.2	5.5	10,373.2	3.58	7
	Licking	735.0	200.6	275.6	30.9	1,242.1	0.43	52
	Madison	1,396.7	15.1	-	22.5	1,434.3	0.49	44
	Pickaway	1,479.6	283.8	-	36.0	1,799.4	0.62	37
	Union	918.7	63.1	-	47.6	1,029.5	0.36	61
	Total Central	**6,393.0**	**2,265.0**	**12,117.7**	**187.7**	**20,963.4**	**7.23**	**5**
Eastern	Belmont	-	216.2	-	7.1	223.3	0.08	82
	Carroll	21.2	111.5	-	8.8	141.5	0.05	84
	Coshocton	278.1	1,641.1	10,924.6	44.3	12,888.1	4.45	5
	Guernsey	25.3	362.9	-	9.9	398.2	0.14	73
	Harrison	-	85.4	-	4.8	90.2	0.03	86
	Holmes	178.0	593.9	421.1	63.9	1,256.8	0.43	50
	Jefferson	12.4	110.8	-	4.6	127.8	0.04	85
	Monroe	8.7	29.9	-	5.1	43.6	0.02	88
	Tuscarawas	101.2	962.0	3,353.4	29.1	4,445.7	1.53	16
	Total Eastern	**625**	**4,113.6**	**14,699.1**	**177.6**	**19,615.2**	**6.77**	**6**
Northern	Erie	440.3	166.6	1,080.4	6.9	1,694.3	0.58	40
	Huron	1,126.7	37.9	-	26.5	1,191.2	0.41	56
	Lorain	303.0	950.9	9,130.9	18.3	10,403.1	3.59	6
	Lucas	474.4	333.5	1,973.3	14.8	2,796.0	0.96	22
	Ottawa	400.4	486.2	5,063.4	6.2	5,956.3	2.06	12
	Sandusky	1,101.4	71.3	-	15.3	1,188.1	0.41	57
	Seneca	1,565.4	118.9	977.8	42.6	2,704.8	0.93	25
	Wood	2,050.1	613.4	6,021.3	11.6	8,696.4	3.00	9
	Total Northern	**7,462**	**2,778.8**	**24,247.0**	**142.4**	**34,630.1**	**11.95**	**4**
Northcentral	Ashland	430.9	60.1	-	38.1	529.1	0.18	68
	Crawford	1,367.3	94.7	655.4	63.0	2,180.4	0.75	33
	Hardin	1,299.1	12.5	-	64.0	1,375.5	0.47	45
	Knox	578.3	66.0	-	33.3	677.6	0.23	66
	Marion	1,101.2	22.5	-	35.8	1,159.5	0.40	58
	Morrow	694.5	15.8	-	23.2	733.5	0.25	64
	Richland	417.5	475.7	3,965.7	28.8	4,887.6	1.69	14
	Wayne	633.1	392.5	1,317.5	109.0	2,452.1	0.85	28
	Wyandot	1,146.2	272.7	2,855.2	59.3	4,333.4	1.50	17
	Total Northcentral	**7,668.0**	**1,412.6**	**8,793.8**	**454.5**	**18,328.8**	**6.32**	**8**

Regions	Counties	Crop Residues	Wood Wastes	MSW[1]	Livestock Manure	Total	% of Total	Rank
North eastern	Ashtabula	161.0	689.0	5,291.7	15.9	6,157.6	2.12	11
	Columbiana	216.0	53.1	-	25.3	294.4	0.10	77
	Cuyahoga	-	611.0	1,850.7	-	2,461.6	0.85	27
	Geauga	14.6	270.4	-	6.8	291.9	0.10	79
	Lake	-	347.8	2,020.8	-	2,368.6	0.82	29
	Mahoning	140.6	2,052.7	19,980.6	12.0	22,186.0	7.66	3
	Medina	120.1	249.2	-	10.4	379.7	0.13	75
	Portage	91.6	134.4	-	7.3	233.4	0.08	81
	Stark	302.3	2,594.6	25,163.5	26.2	28,086.6	9.69	2
	Summit	-	458.0	1,886.7	0.3	2,344.9	0.81	30
	Trumbull	195.7	407.8	710.6	8.6	1,322.7	0.46	47
	Total Northeast	**1,242**	**7,868.0**	**56,904.6**	**112.8**	**66,127.4**	**22.82**	**1**
North western	Allen	1,064.9	80.1	-	46.7	1,191.8	0.41	55
	Defiance	886.6	240.3	2,315.3	17.0	3,459.1	1.19	19
	Fulton	1,484.0	14.4	-	85.2	1,583.6	0.55	41
	Hancock	1,641.6	136.5	973.2	37.7	2,789.0	0.96	23
	Henry	1,698.6	35.1	212.6	16.2	1,962.4	0.68	35
	Paulding	1,187.3	60.5	580.7	14.0	1,842.6	0.64	36
	Putnam	1,688.9	10.8	-	79.4	1,779.1	0.61	39
	Van Wert	1,446.7	9.3	-	20.4	1,476.4	0.51	43
	Williams	821.2	187.5	1,556.4	23.3	2,588.4	0.89	26
	Total Northwest	**11,920**	**774.5**	**5,638.1**	**339.9**	**18,672.4**	**6.44**	**7**
Southern	Adams	131.7	157.7	-	19.5	308.9	0.11	76
	Gallia	18.2	2,706.6	25,866.2	7.2	28,598.2	9.87	1
	Highland	607.8	90.7	-	15.8	714.3	0.25	65
	Jackson	7.7	581.1	2,183.2	2.0	2,773.9	0.96	24
	Lawrence	-	86.7	-	1.2	87.9	0.03	87
	Pike	12.4	598.6	2,539.6	3.2	3,153.8	1.09	20
	Ross	857.0	1,233.2	-	13.5	2,103.7	0.73	34
	Scioto	50.2	789.2	-	1.9	841.3	0.29	62
	Total South	**1,685**	**6,243.7**	**30,589.0**	**64.3**	**38,581.9**	**13.31**	**3**
South eastern	Athens	15.1	350.8	1,417.0	3.1	1,786.0	0.62	38
	Hocking	0.1	521.8	-	0.7	522.6	0.18	69
	Meigs	7.7	252.8	-	3.2	263.7	0.09	80
	Morgan	14.4	139.9	-	11.0	165.3	0.06	83
	Muskingum	176.2	203.5	-	22.2	402.0	0.14	72
	Noble	-	291.6	-	2.2	293.8	0.10	78
	Perry	245.6	834.6	6,453.4	8.3	7,541.9	2.60	10
	Vinton	2.7	452.5	-	0.6	455.8	0.16	71
	Washington	74.8	376.8	-	14.8	466.4	0.16	70
	Total Southeastern	**537**	**3,424.3**	**7,870.4**	**66.1**	**11,897.4**	**4.11**	**10**

Regions	Counties	Crop Residues	Wood Wastes	MSW[1]	Livestock Manure	Total	% of Total	Rank
South western	Brown	272.6	209.1	1,796.5	8.6	2,286.9	0.79	31
	Butler	411.7	197.9	-	20.5	630.1	0.22	67
	Clermont	100.7	454.2	4,108.2	2.4	4,665.5	1.61	15
	Clinton	1,126.3	47.0	123.2	31.6	1,328.1	0.46	46
	Fayette	1,282.8	9.5	-	25.5	1,317.9	0.45	48
	Greene	896.2	173.3	-	27.4	1,096.9	0.38	60
	Hamilton	-	2,069.8	19,573.6	0.5	21,643.9	7.47	4
	Montgomery	486.7	955.9	8,440.0	16.0	9,898.6	3.42	8
	Preble	1,134.0	54.8	315.6	68.8	1,573.2	0.54	42
	Warren	293.1	97.7	-	7.3	398.2	0.14	74
	Total South western	**6,004**	**4,269.2**	**34,357.2**	**208.7**	**44,839.2**	**15.47**	**2**
Western	Auglaize	1,063.8	86.3	-	64.0	1,214.0	0.42	54
	Champaign	1,205.7	15.1	-	31.6	1,252.5	0.43	51
	Clark	997.6	90.6	-	17.6	1,105.8	0.38	59
	Darke	2,010.1	28.6	-	178.4	2,217.1	0.77	32
	Logan	983.3	425.7	3,480.9	31.0	4,920.9	1.70	13
	Mercer	1,591.5	140.3	1,008.7	193.4	2,933.9	1.01	21
	Miami	1,198.4	34.8	-	55.7	1,289.0	0.44	49
	Shelby	1,130.8	17.1	-	67.4	1,215.3	0.42	53
	Total West	**10,181**	**838.5**	**4,489.6**	**639.1**	**16,148.6**	**5.57**	**9**
Ohio	**Total**	**53,716.8**	**33,988.0**	**199,706.6**	**2,393.0**	**289,804.4**	**100**	**-**

[1]: MSW wood wastes excluded

8.- Concluding remarks

The purpose of the study was to estimate the biomass resources in Ohio for energy potential. To this end, secondary data were collected to estimate crop residues, wood wastes, municipal solid wastes, and methane from livestock manure. Initial efforts to obtain detailed information on the quantity and location of Ohio's food waste biomass resource were slowed due to a very low response rate to the food waste biomass survey. This situation led to the formulation of a two-phase approach to the food processing waste component of the overall biomass study. The first phase was conducted in this study, with estimates of the food waste resource (quantity and geographic distribution) detailed primarily with GIS maps.

The results indicate that even after accounting for competing uses and allowing for environmental sustainability, Ohio has significant biomass energy potential. It is worth noting that corn and wheat are only two crops considered in the study. Other agricultural residues and energy crops could constitute important biomass feedstocks. Also the Ohio predominant animal waste which is chicken manure/bedding is not taken into consideration due to data limitation at the county level. The study relies on a set of assumptions and the results should be judged accordingly even though the authors have tried to consistently make conservative estimates.

It can be concluded that when done in a way accounting for competing uses, biomass feedstock can offset petroleum fossil CO_2, and reduce Ohio's dependence on petroleum. However, a number of issues must be considered. The amount of crop residues to be available depends on farmers' attitude regarding tillage practices. Removing too many crop residues and implementing some tillage practices may lead to soil degradation and nutrient depletion. Although, the study identifies each county's potential for sustainable and usable crop residues for energy, crop residue removal might actually be better in counties where low or no-till is practiced. Due to limited information, the study failed to identify the tillage practiced in each county.

The study does pinpoint the counties or regions in which biomass resources are concentrated. However, in terms of energy conversion plant locations, more detailed analysis would be required and more GIS procedures to determine the optimal location of biomass facilities within a reasonable radius would need to be implemented. For example, for installing an ethanol plant in a region, water and power availability in the region is critical, assuming a useable sustainable supply of residues given alternative uses for the residues. The location and supply sources of existing biomass conversion to energy plants also need to be known.

If the producer has to collect, haul and transport the corn stover; an incentive maybe required. When collecting and transporting crop residues, appropriate equipment must be used to limit soil compaction that can result in water runoff, soil erosion and thereby reduce yield in the future. The producer must be willing to cooperate by entering an agreement with biofuel producers to provide the feedstocks on a long-term basis. He or she will choose to do so only if the discounted net benefits turn out to be positive. For this reason MSW, food processing and wood wastes are relatively attractive energy feedstocks since they are already concentrated in centralized locations.

An extension of this study could focus on these aspects as well as implementing the second phase of the food processing wastes survey. The maps produced along with feedback obtained from Frito Lay's completion of the biomass survey (see the completed survey in Appendix A-2) should guide future efforts at obtaining actual data on the food waste biomass resource.

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Appendices

A-1: Cover letter and Food Waste Survey Questionnaire

State of Ohio Food Waste Biomass Survey

Thank you for participating in the State of Ohio food waste biomass survey. This study is being conducted by Ohio State University in conjunction with the Ohio Department of Development and EISC. The information collected from the survey will allow us to assess the feasibility of a food waste-to-energy program in the State of Ohio.

To complete the survey, simply enter your responses in the shaded text boxes. When you are finished, save the document and email it to warren.218@osu.edu. Or, if you prefer, you can print the survey and complete it by hand. Should you choose this method, return the survey by mail to: David Warren, 227 Agricultural Administration, 2120 Fyffe Road, Columbus, OH 43210.

If you have any questions about this survey or the biomass energy program, do not hesitate to contact any of the people listed below. Again, thank you so much for your time and participation in this study.

Sincerely,

Dave Warren (Ohio State University)
Warren.218@osu.edu

Fred Hitzhusen (Ohio State University)
Hitzhusen.1@osu.edu

Dave Beck (EISC)
Dave.beck@eisc.org

Mike Salva (Ohio Department of Development)
msalva@odod.state.oh.us

State of Ohio Food Waste Biomass Survey

1. What zip-code is your plant located in?

   44691

2. What are the main end-products that your plant produces?

   1 Potato Chips
   2 Corn Chips
   3 Wet Waste
   4 Non-Food Grade Starch
   5

3. Food waste-to-energy conversion technologies vary depending upon the characteristics and composition of the food wastes. What is your best estimate of the % of all food waste that your company produces for the following four categories:

Percent	**Type**		**Characteristics**
0 %	Wet fluid/liquid.	Flows	No suspended particulates/solids.
5 %	Semi-fluid wet	Slow flow	Gel or suspended solids, slow flow, paste, may separate in water
30 %	Semi-dry	Damp solid	Damp particles, powders. Won't flow, won't tumble readily, is solid, particulate, no separable water/fluid, packs on compression.
70 %	Dry	Dry particles	Discrete granules, particles, easily moved by scooping, augering, conveyer belt, non-packing upon compression.

4. Please describe the content of your food wastes. Include your estimate of the % water content of the waste and the composition of the waste. For instance, if the waste is vegetable waste that is mostly liquid, you would write "Vegetable Waste" followed by the composition, say 80% water content, 10% tomatoes, 5% onions, 5% other. Obviously, you may not know the exact composition, but please provide the best estimate you can. Also, be as specific as you can about the composition. In other words, if part of the composition is tomatoes, please provide what part of the tomato (skins, pulp, seeds, etc.).

Food Waste	Water Content		Composition
Potato Chips	0	%	98 % Potato, 1% Salt, 1% Seasonings
Corn Chips	0	%	98% Corn Masa, 1% Salt, 1% Seasonings
		%	
		%	
		%	

5. For the food wastes you described in question 4 above, about how much is produced every year? **Please be specific about the type of unit you are using** (weight, volume, heat value, etc.)

Food Waste	Amount/Year
PC & Corn Finished Waste	4,665,373 lbs.
Wet PC & Corn Waste	9,518,666 lbs.
Non Food Grade Starch	2,407,887 lbs.

6. Are there significant variations in the amount of food waste produced throughout the year? If so, please comment. For instance, some food processing plants may produce 50% of one type of product in one season, resulting in more food waste during that season than the rest of the year.

No variation

7. For each of the types of food wastes that you have identified, can you tell us a little about what you currently do with the wastes? Use the categories listed below and/or use the 'other comments' column to be more specific.

1. Sell the wastes
2. Pay to dispose of the wastes
3. Dispose of the wastes at no cost
4. Use the wastes for other purposes in your plant
5. Compost the wastes

Food Waste	Current Use(s)	Other Comments
PC & Corn Dry Waste	1.	
PC & Corn Wet Waste	2.	
Non – Food Grade Starch	1.	

8. If possible, please tell us a little about the costs or benefits of your food wastes. For each waste, please tell us how you use the waste (sell, pay to dispose of, use, etc.) and how much money PER UNIT (be specific about the unit) you are paid for the waste or that you must pay to dispose of it.

Food Waste	Use	$/unit (if applicable)
PC & Corn Dry Waste	Sold for animal feed	.565 per 1,000 lbs.
PC & Corn Wet Waste	Pay to dispose of	.516 per 1,000 lbs.
Non-Food Grade Starch	Sold for other uses	3.63 per 1,000 lbs.

9. In light of increased fossil fuel imports, rising fossil fuel prices, and the financial and environmental costs of waste disposal, the State of Ohio is investigating a biomass energy program to convert waste streams, including food wastes, into energy using conversion technology that would be located in optimal locations throughout the state. If such a program would provide payments to your company's food wastes, how supportive would you be of the program? (place an X in one box)

- [X] Extremely Supportive
- [ ] Very Supportive
- [ ] Somewhat Supportive
- [ ] Not Very Supportive
- [ ] Not At All Supportive

10. If the biomass energy program were implemented and the State of Ohio paid food processing facilities for waste, what is the minimum amount of money per unit of waste that would be required for you to be willing to participate in the program?

I would be willing to participate in the program if the State of Ohio paid my company

$ [?] per [1000 lbs] of waste.

11. How many employees work in your plant?

[350] Employees

12. What is the normal production cycle duration for your plant? In other words, what is the length of time that your plant produces food wastes before shutting down for cleaning, seasonal change, etc. Please be as specific as possible.

In the summer we run 13 days on 1 day off for cleaning for each line (Corn & PC).
Through the rest of the year we typically run 6 days per week 1 day off for cleaning.

13. If some of your food wastes are produced seasonally, please tell us what time of year such wastes are produced.

Food waste	Seasonality

Thank you for completing the survey. Your responses will help determine if a food waste-to-energy program is feasible and economical in the State of Ohio.

Now, please save the document and email it back to warren.218@osu.edu. Thanks again!

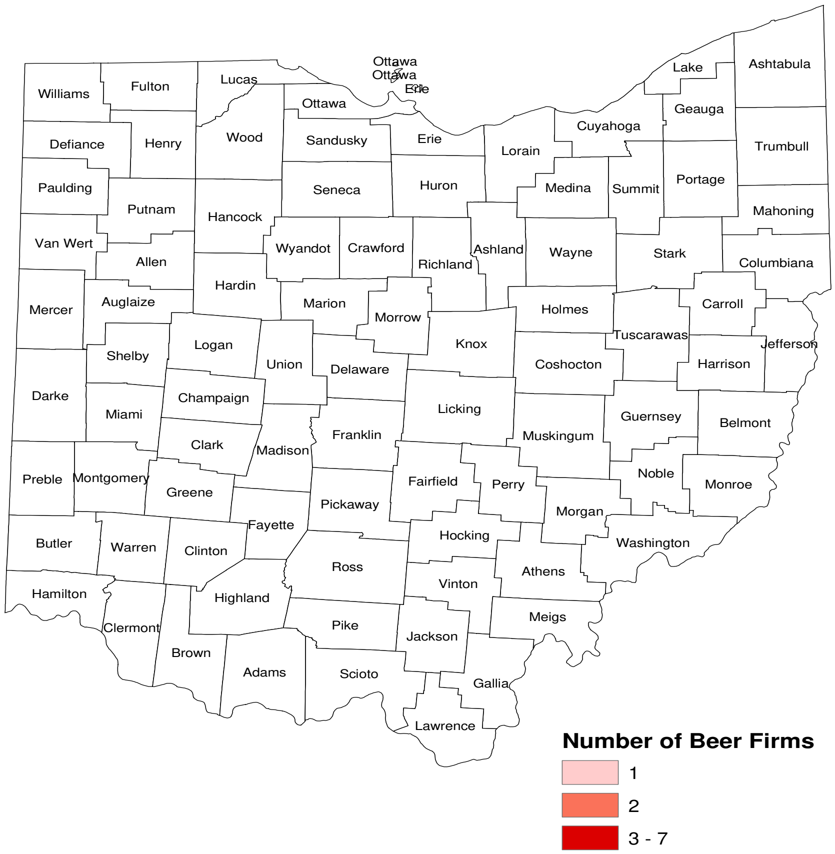
A-3: Maps of other types of food processing waste companies

Number of Cereal Firms by County, 2003

Number of Cereal Firms

1

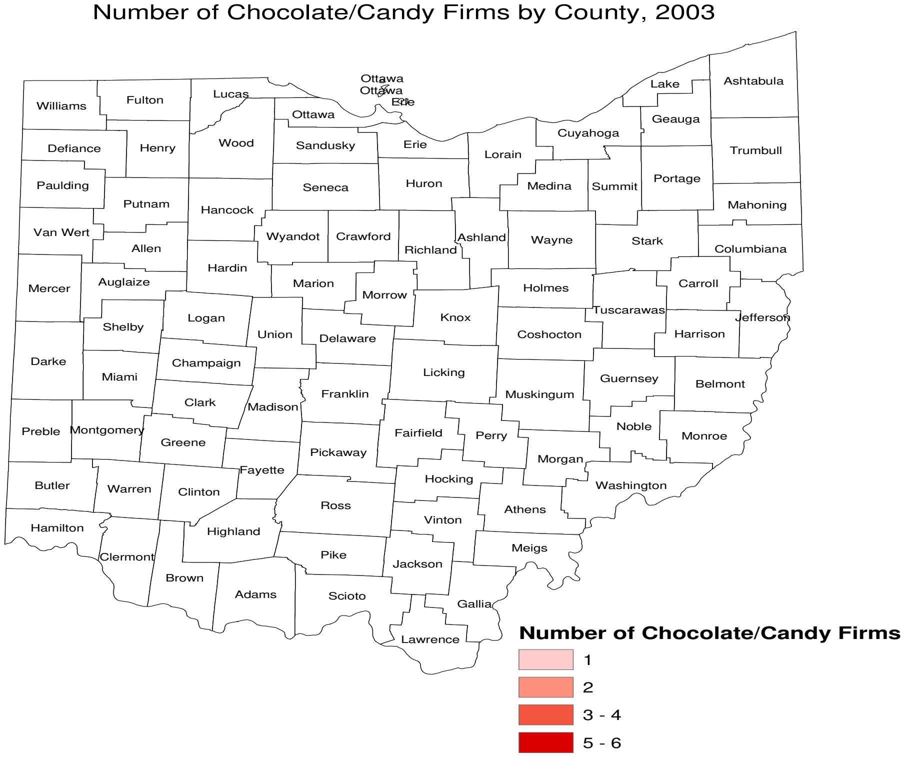
Number of Beer Firms, 2003



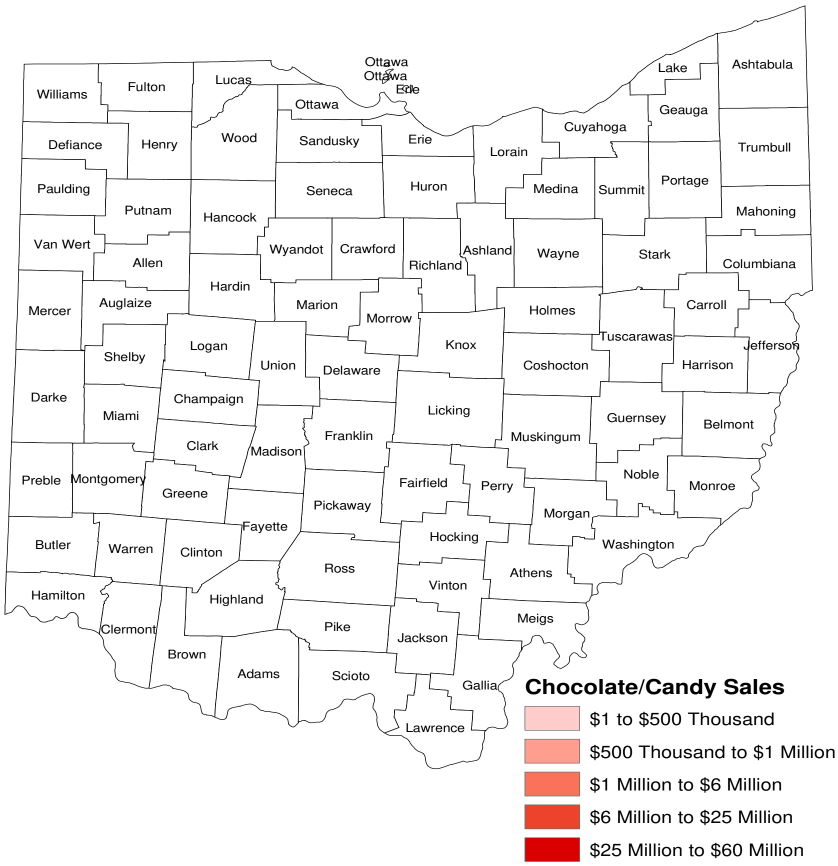
Estimated Minimum Beer Sales, 2003

Estimated Minimum Cereal Sales by County, 2003

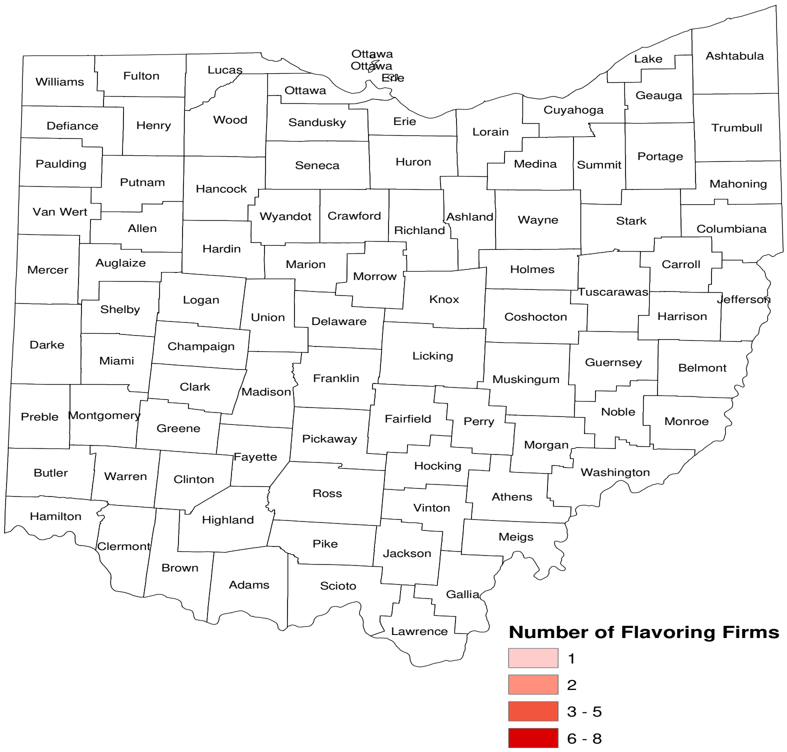
Number of Chocolate/Candy Firms by County, 2003



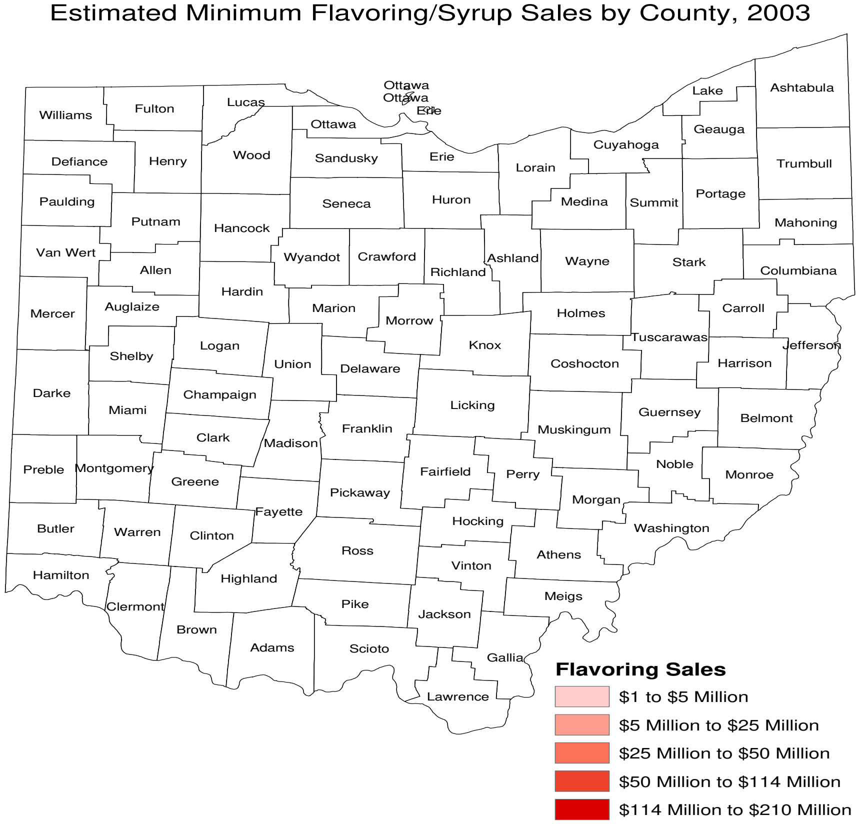
Estimated Minimum Chocolate/Candy Sales by County, 2003



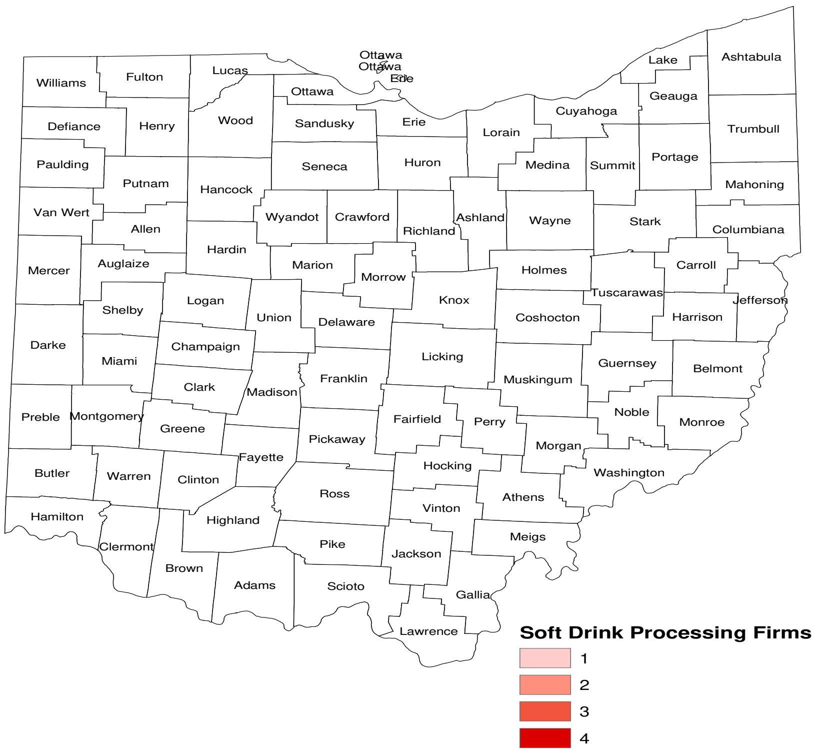
Number of Flavoring/Syrup Firms by County, 2003



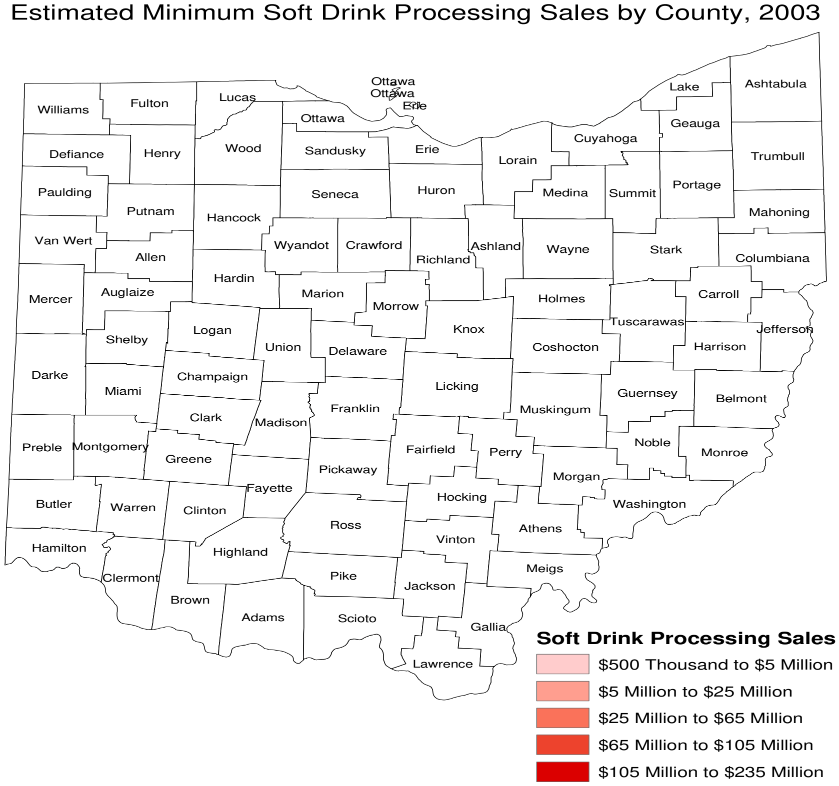
Estimated Minimum Flavoring/Syrup Sales by County, 2003



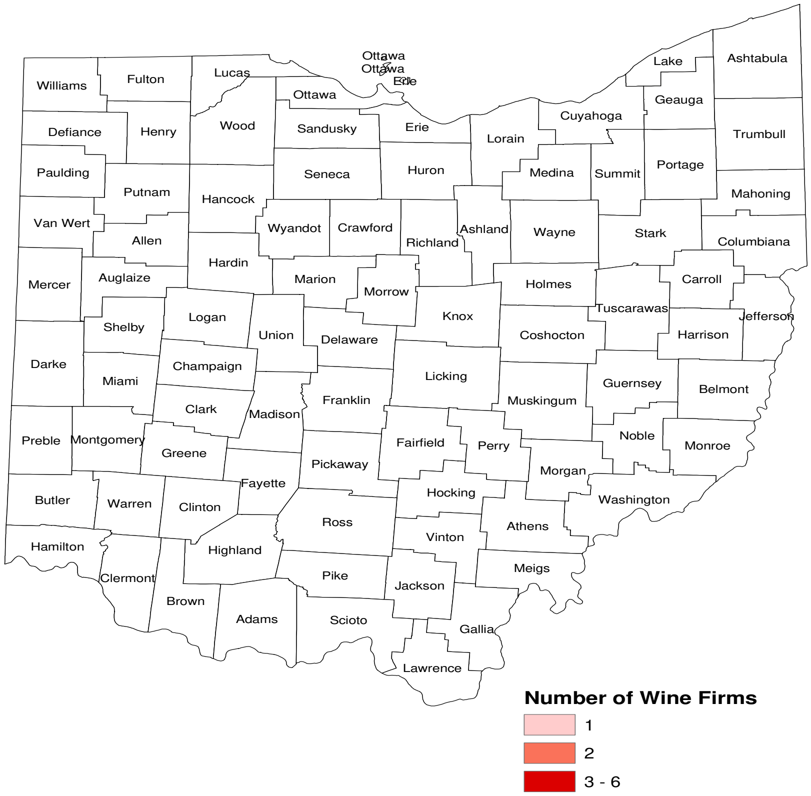
Number of Soft Drink Processing Firms by County, 2003



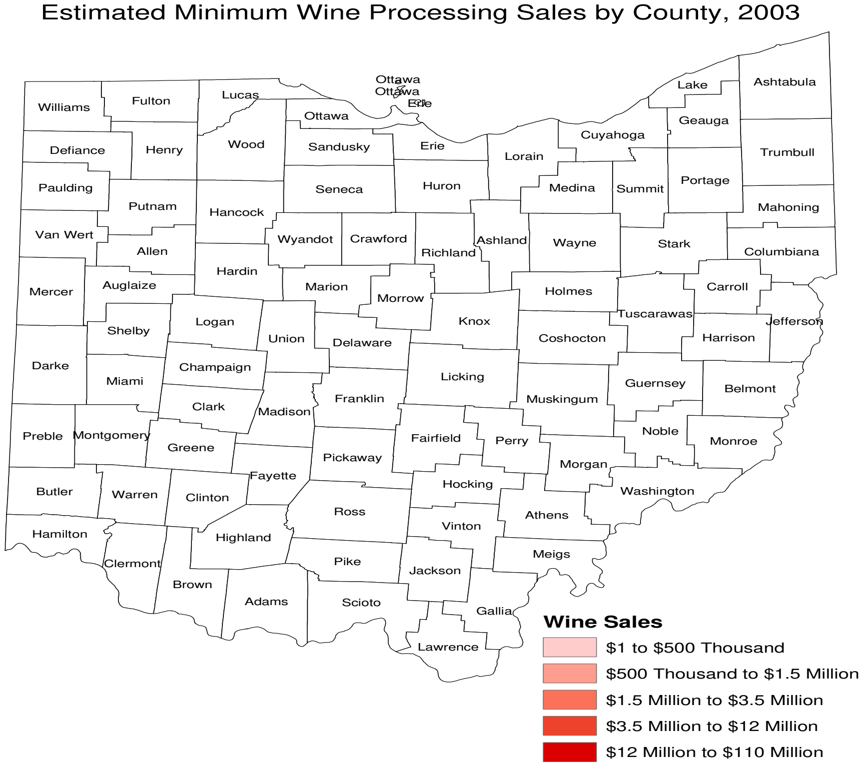
Estimated Minimum Soft Drink Processing Sales by County, 2003



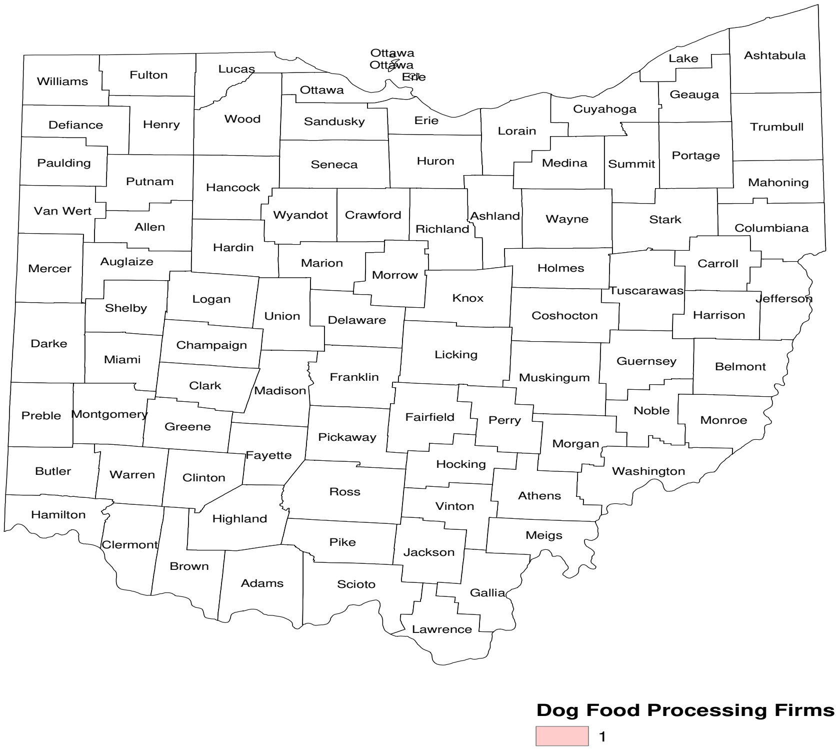
Number of Wine Processing Firms by County, 2003



Estimated Minimum Wine Processing Sales by County, 2003



Number of Dog Food Processing Firms by County, 2003



Estimated Minimum Dog Food Processing Sales by County, 2003