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A Geographic Perspective on the Current Biomass Resource Availability in the United States

A. Milbrandt

Technical Report
NREL/TP-560-39181
December 2005

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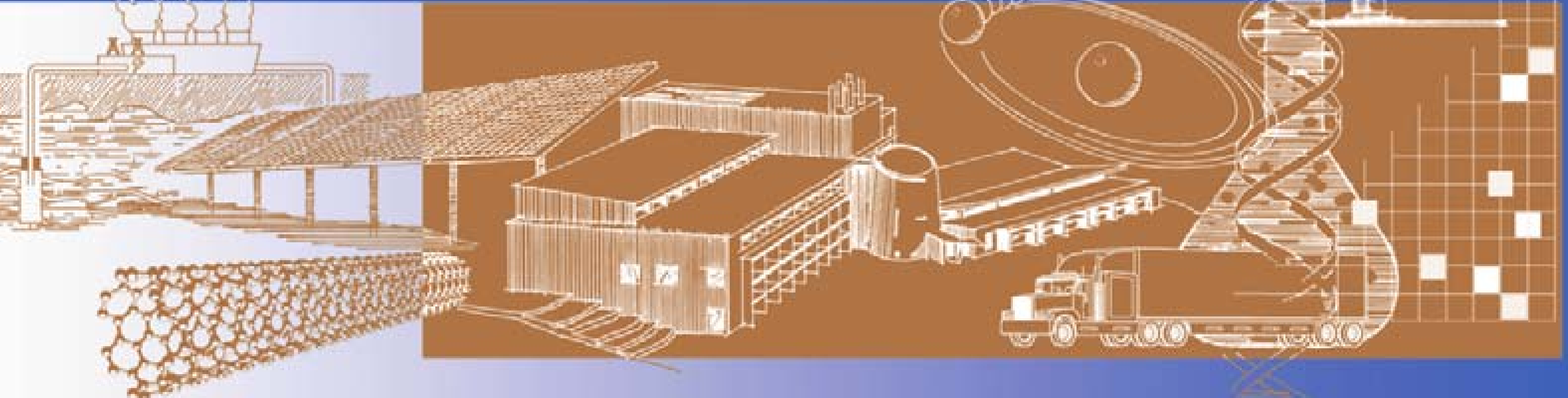

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Introduction

Biomass is receiving increasing attention as scientists, policy makers, and growers search for clean, renewable energy alternatives. Compared with other renewable resources, biomass is very flexible; it can be used as fuel for direct combustion, gasified, used in combined heat and power technologies, or biochemical conversions. Due to the wide range of feedstocks, biomass has a broad geographic distribution, in some cases offering a least-cost and near-term alternative.

The objective of this research is to estimate the biomass resources available in the United States and map the results. To accomplish this objective, biomass feedstock data are analyzed both statistically and graphically using geographic information systems (GIS). A GIS is a computer-based information system used to create, manipulate, and analyze geographic information, allowing us to visualize relationships, patterns, or trends that are not possible to see with traditional charts, graphs, and spreadsheets.

While other biomass resource assessments concentrate on the economic or theoretical availability, this study estimates the technical biomass resources available in the United States (page 59). The estimates are based on numerous assumptions, methodologies adopted from other studies, and factors that relate population to the amount of post-consumer residue generation. The main contribution of this research is that it adds a geographic perspective to biomass research by answering questions such as where the resources are and how much is available.

Factors Determining the Geographic Distribution of Biomass

The geographic distribution and quantity of biomass depend on the relationship between ecological zones and the climate conditions, which is complex and linked into an ecotype as shown in the following Figure[1]:

[1] Schultz, J. (2005). The Ecozones of the World: the ecological divisions of the geosphere. Heidleberg, DE, Springer

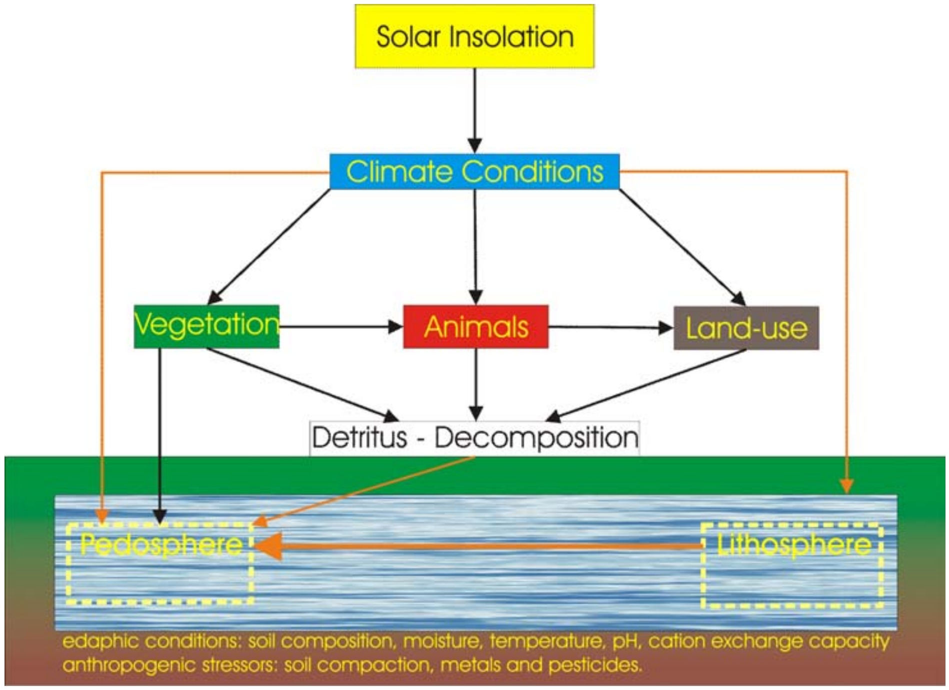

Figure 1 Ecological Divisions of the Geosphere

The climate zones of the United States are shown in Figure 2, ranging from polar in Alaska to tropical in Hawaii. Each zone is characterized by a certain pattern of weather conditions, seasons, and weather extremes like hurricanes, droughts, or rainy periods. The climate parameters of temperature (Figure 3), precipitation (Figure 4), and insolation (Figure 5), combined with elevation (Figure 6) and soils (Figure 7) are interwoven to create ecoregions (Figure 8). The present land use resulting from these ecosystem–ecotype interactions with the large increase in human population following colonization of the United States by Europeans is shown in Figure 9.

The proportion of people living in metropolitan areas greater than 50,000 persons is now 80% (2000 census); the locations of these urban centers are shown in Figure 10. This concentration of population and activities in urban areas is responsible for the generation of residues. Residues take many forms including urban wood (shipping pallets, construction and demolition, utility right of way clearance, and tree trimming); the biomass portion of household garbage (paper, food, textiles, and yard trimmings), as well as the sludge from municipal water treatment and landfill gases. The amount of municipal residues generated is often described in the statistics as MSW (municipal solid waste) despite ever increasing re-use, recycling, materials recovery, and energy generation. The amount of material in any metropolitan area is related to the individual household size and income. As a general rule, a higher standard of living results in more waste; this is especially true for a high consuming society like the United States. Population growth, increasing urbanization, and the movement towards environmental sustainability have made the disposal of waste a controversial issue. Socio-economic drivers such as government policy and social acceptance play a very important role in minimizing the generation of wastes and reducing landfilling by recycling and combustion to generate electricity.

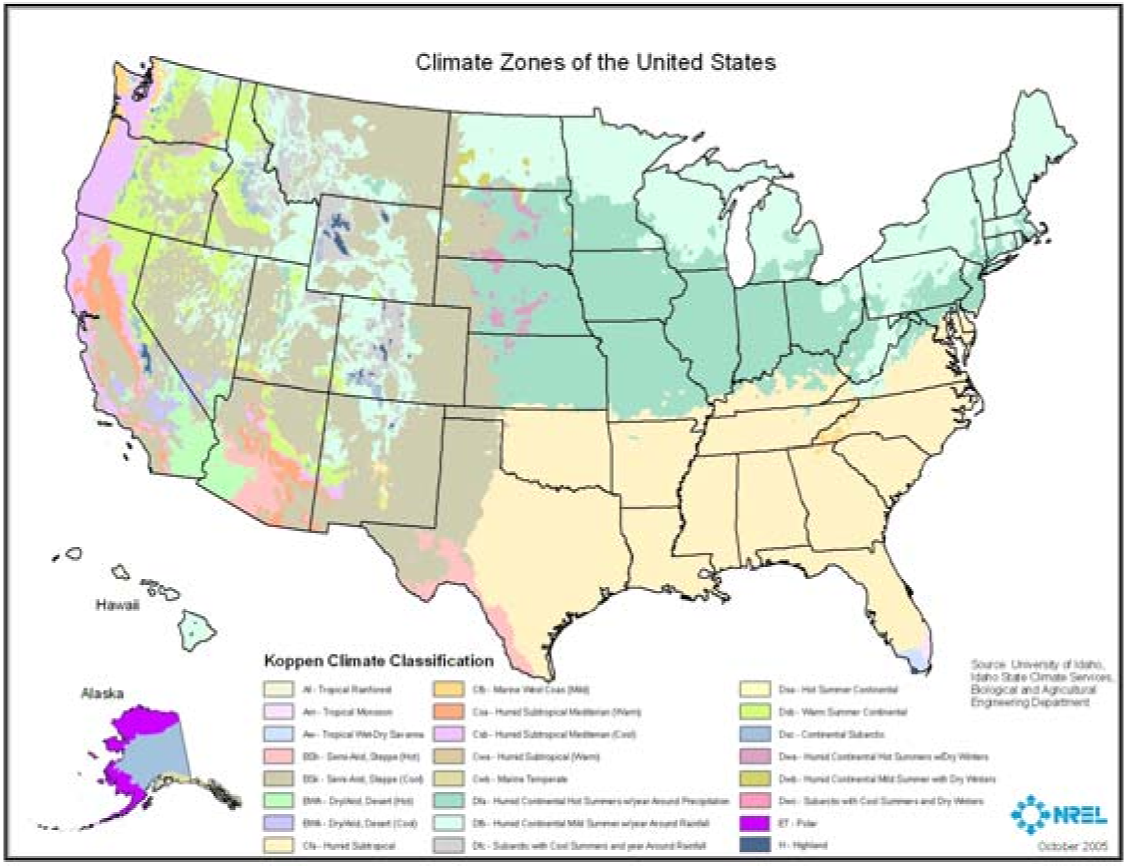

Figure 2 Climate Zones of the United States

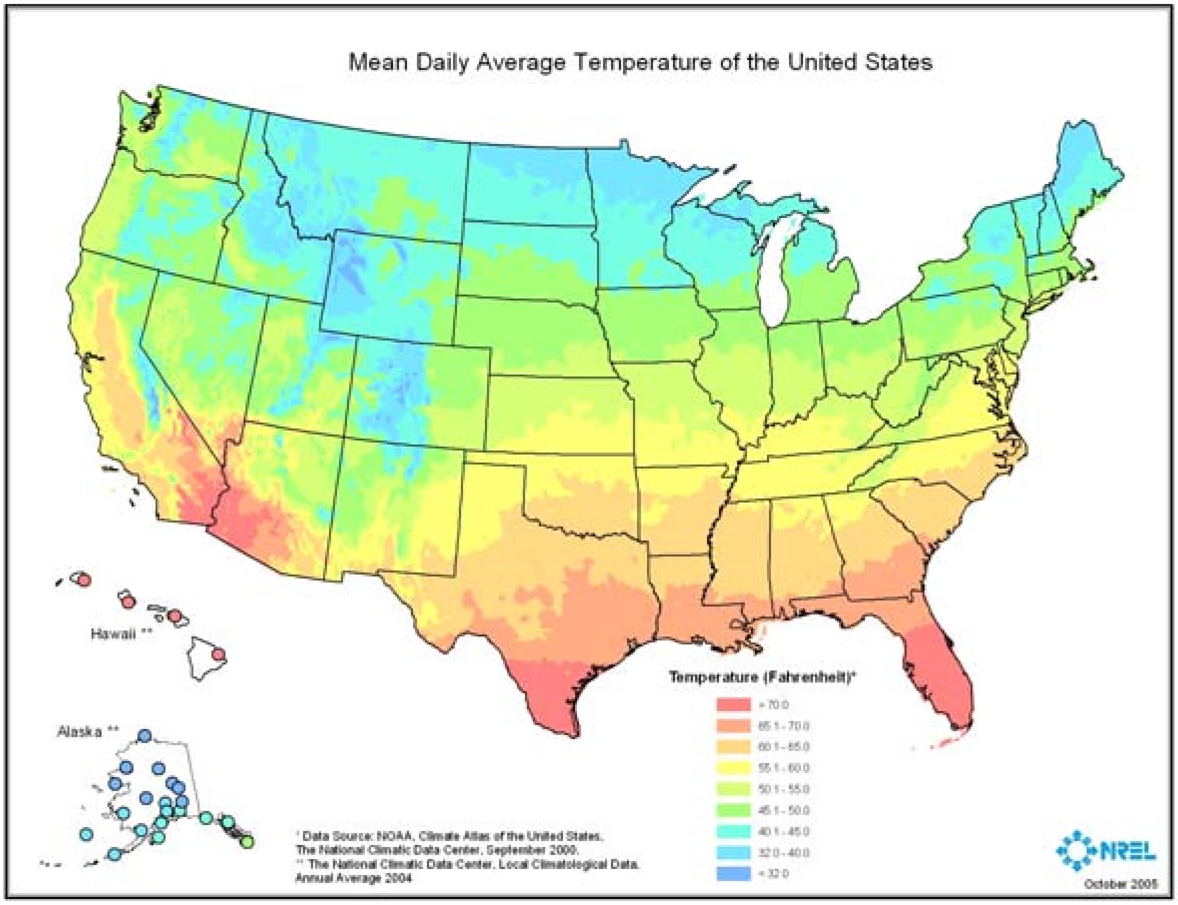

Figure 3 Mean Daily Average Temperature of the United States

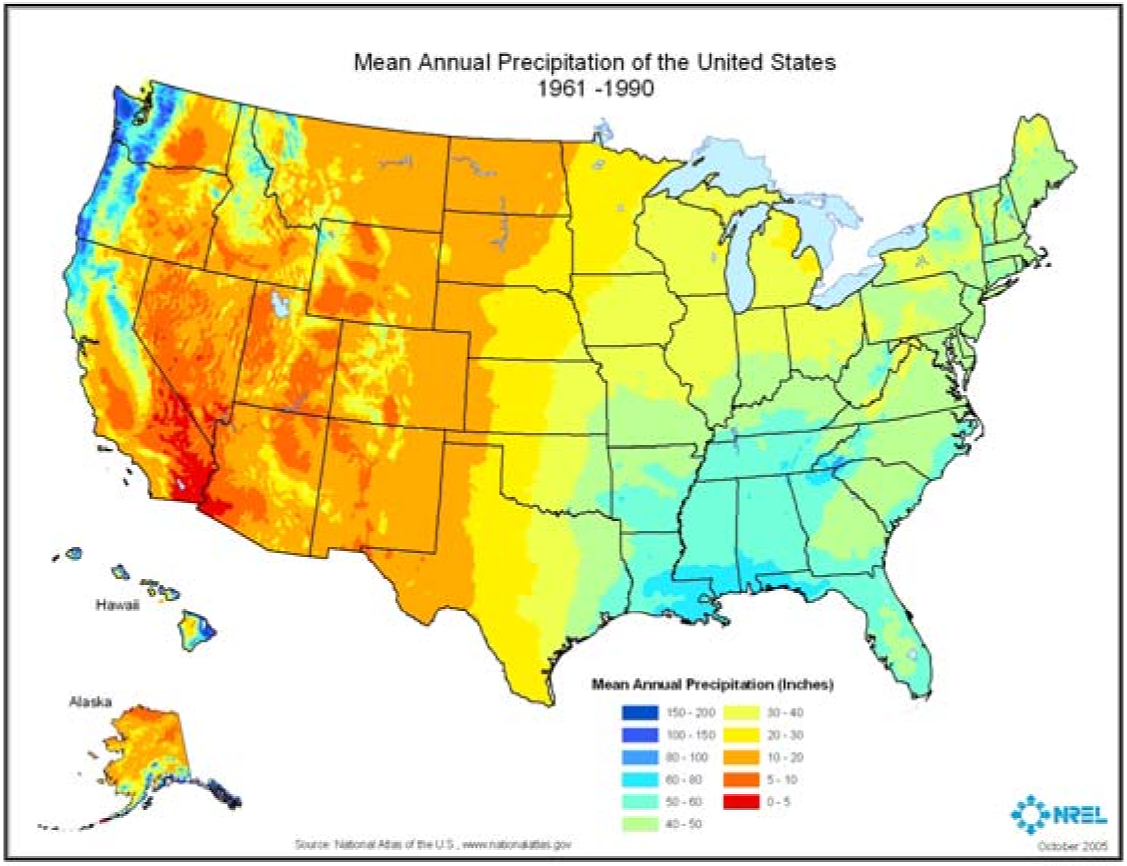

Figure 4 Mean Annual Precipitation of the United States

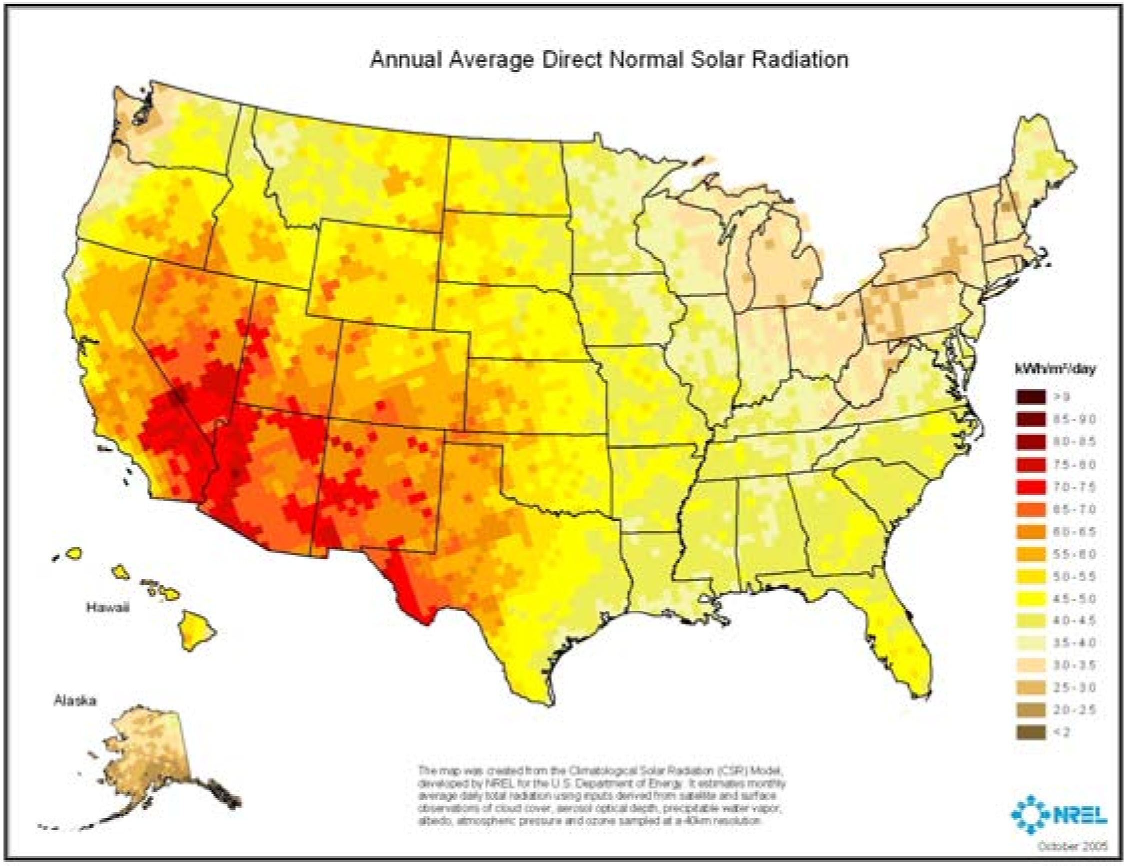

Figure 5 Annual Average Direct Normal Solar Radiation

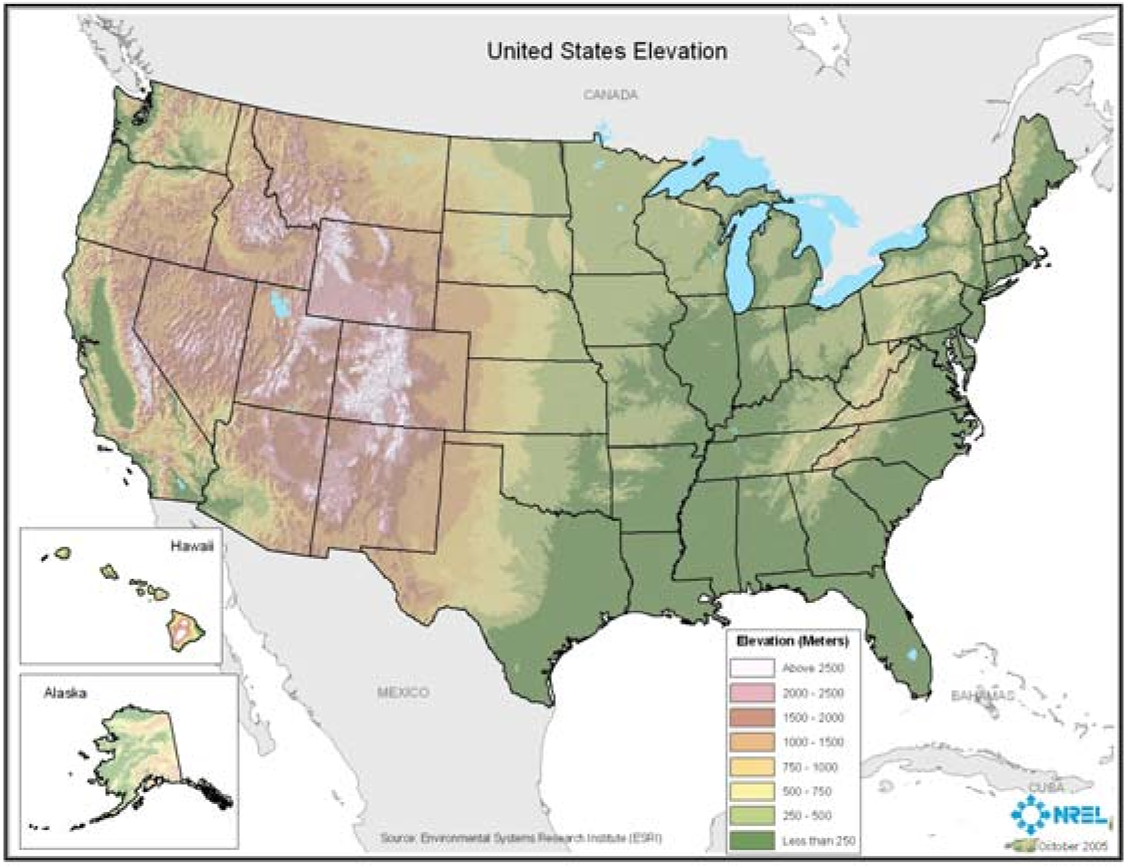

Figure 6 United States Elevation

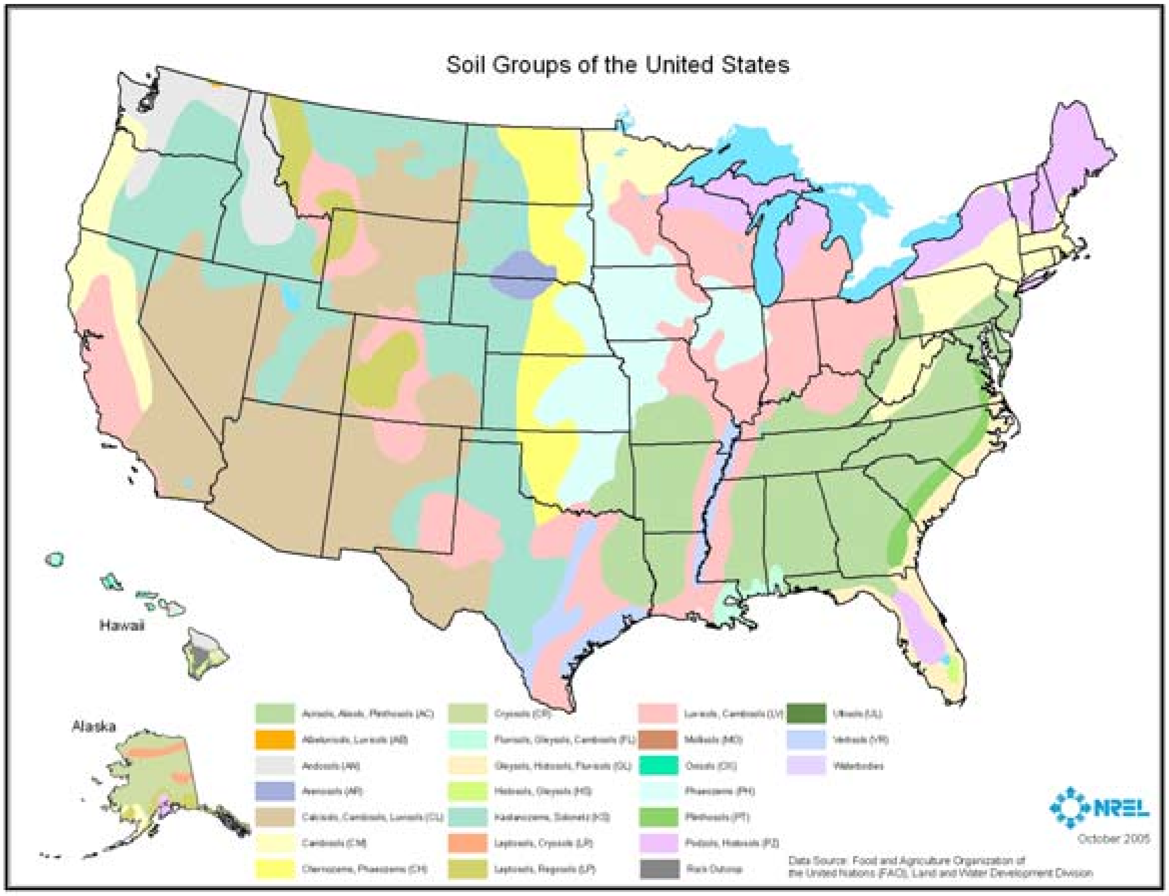

Figure 7 Major Soil Groups of the United States

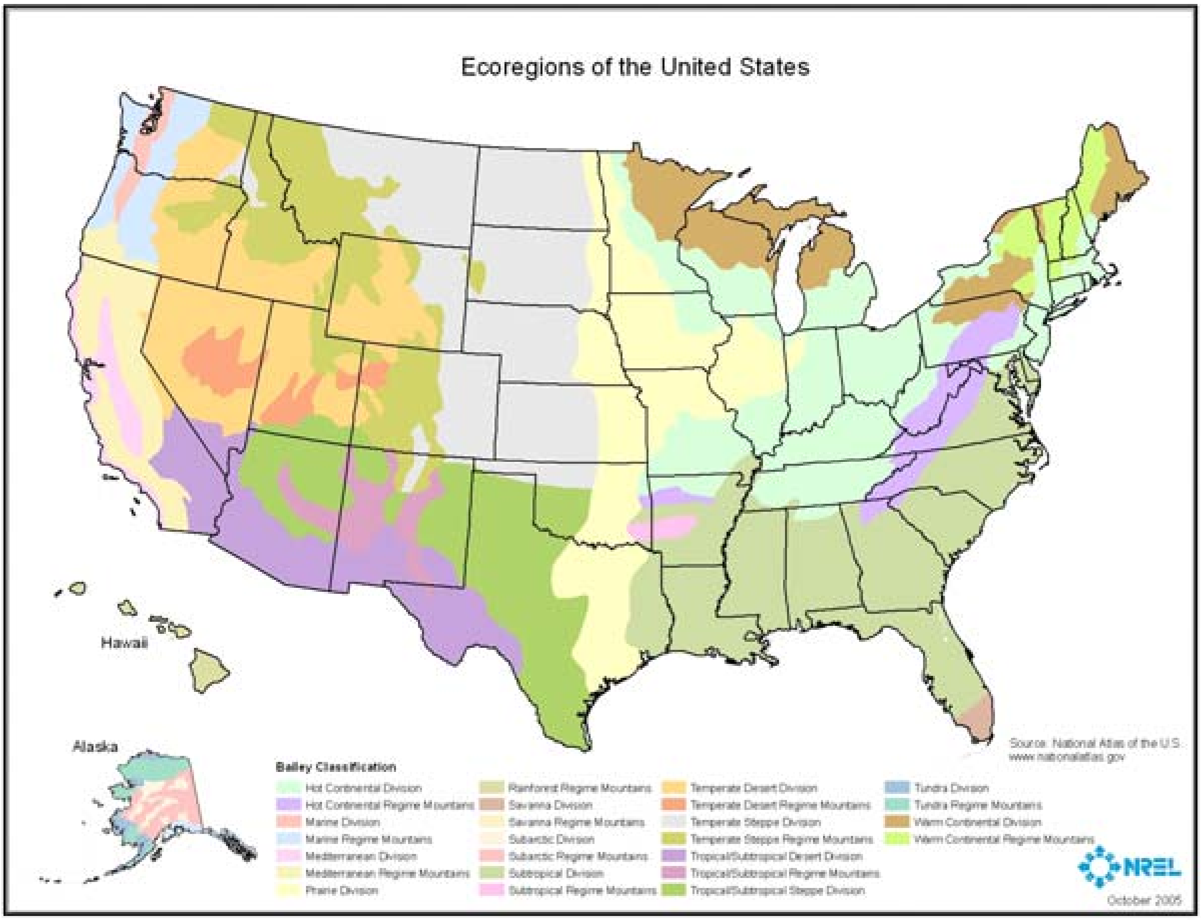

Figure 8 Ecoregions of the United States

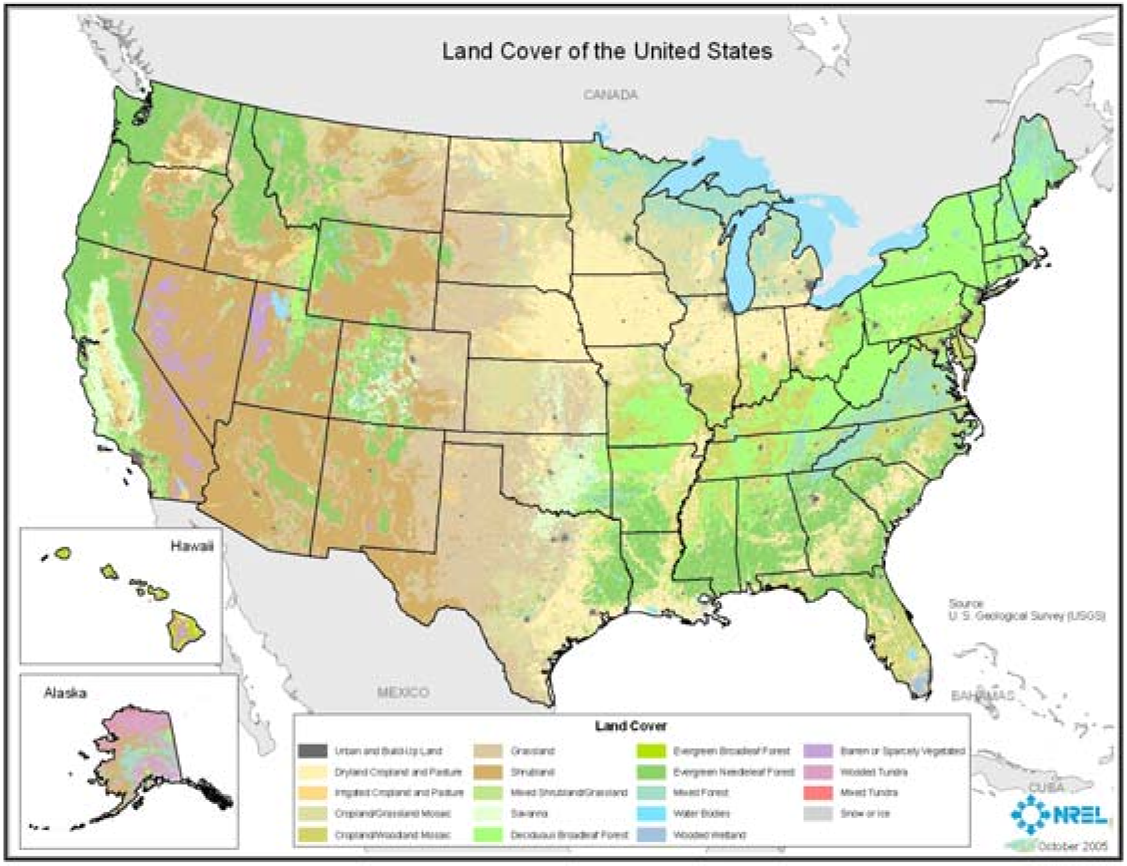

Figure 9 Land Cover of the United States

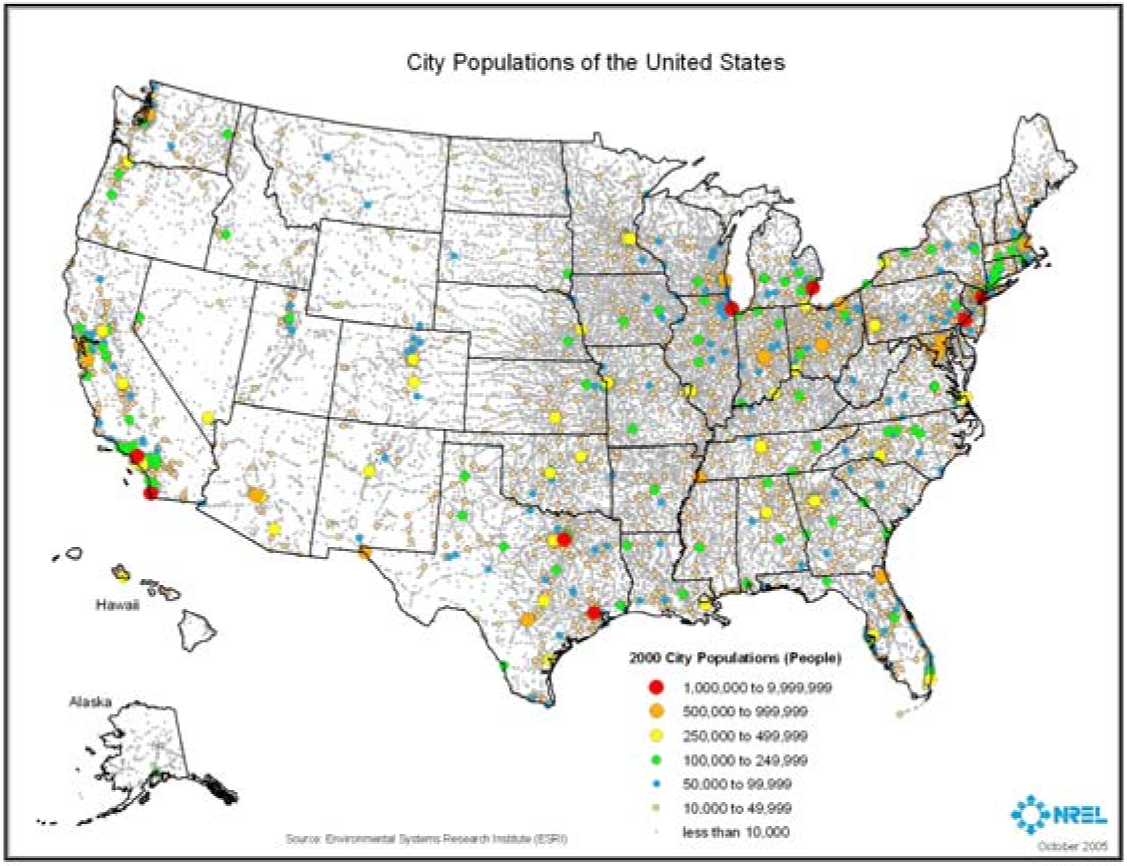

Figure 10 City Populations of the United States

Biomass Resource Availability in the United States

For the purpose of this study biomass feedstocks were divided into the following categories:

Agricultural residues
- Plant based (crop residues)
- Animal based (methane emissions from manure management)

Wood residues
- Forest residues
- Primary mill residues
- Secondary mill residues
- Urban wood residues

Municipal Discards
- Methane emissions from landfills
- Methane emissions from domestic wastewater treatment

Dedicated Energy Crops Case Studies
- Conservation Reserve Program (CRP) lands
- Abandoned mine lands

Agricultural Residues

Crop Residues

The following crops are included in this analysis: corn, wheat, soybeans, cotton, sorghum, barley, oats, rice, rye, canola, beans, peas, peanuts, potatoes, safflower, sunflower, sugarcane, and flaxseed. The quantities of crop residues that can be available in each county were estimated using total grain production, crop to residue ratio, moisture content, and taking into consideration the amount of residue left on the field for soil protection, grazing, and other agricultural activities. All estimates were developed using total grain production by county for 2002 reported to the U.S. Department of Agriculture. Quantities that must remain on the field for erosion control differ by crop type, soil type, weather conditions, and the tillage system used. It was assumed that 30% residue cover is reasonable for soil protection[2]. Animals seldom consume more than 20%-25% of the stover in grazing, and we presume about 10%-15% of the crop residue is used for other purposes: bedding, silage, etc. Therefore, it was assumed that about 35% of the total residue could be collected as biomass. The amount of crop residues available by county is shown on Figure 11. For details on the applied methodology, please refer to the Analysis Methodology section of this paper (page 51).

[2] In general, tillage practices that maintain between 30% and 50% ground cover throughout the period when no crop is growing will adequately protect soil from erosion due to wind and water.

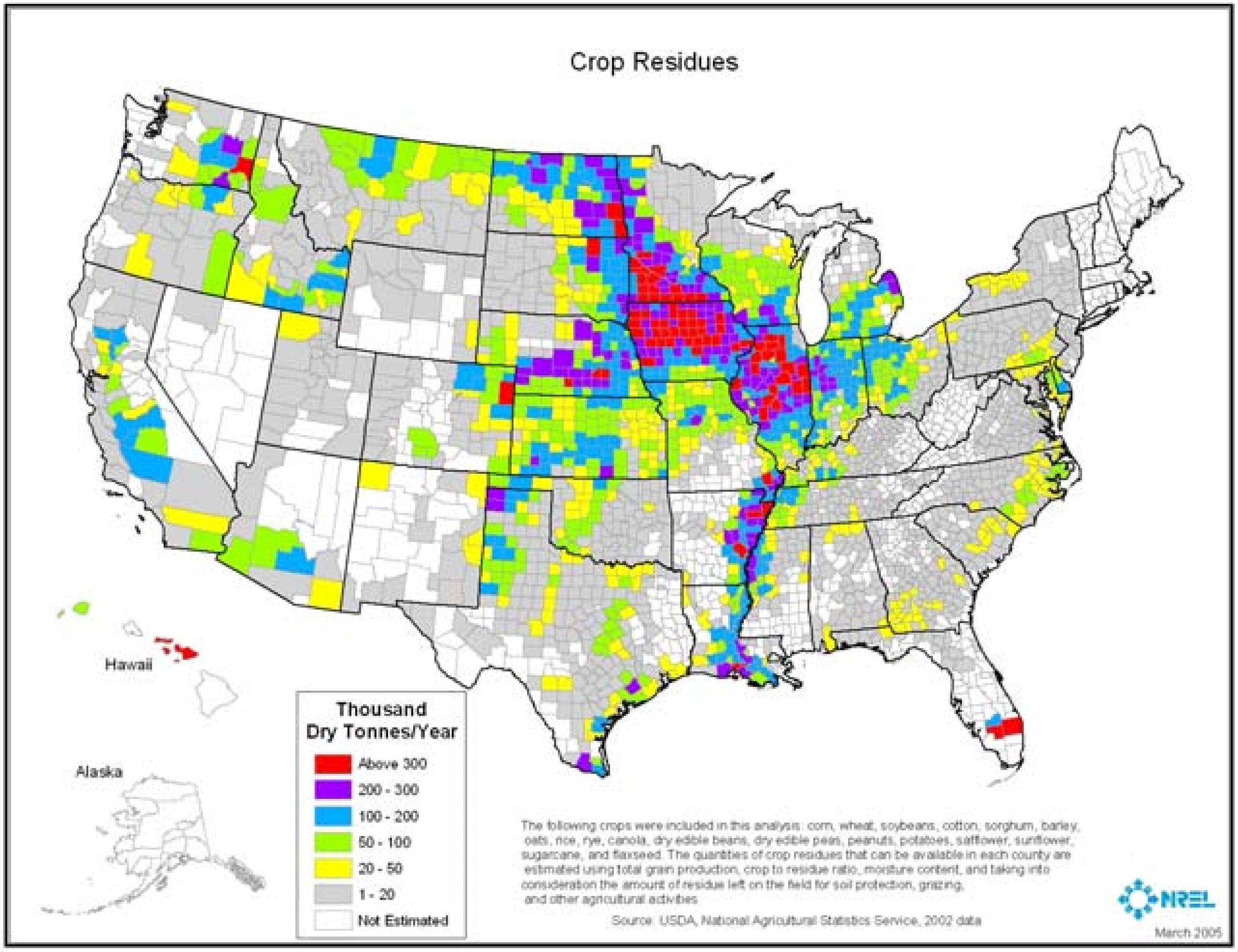

Figure 11 Estimated Crop Residues by County

Table 1 Estimated Crop Residues by State

State	Crop Residues (Thousand Dry Tonnes)
Alabama	391
Alaska	0
Arizona	351
Arkansas	4,796
California	1,659
Colorado	1,550
Connecticut	0
Delaware	245

District of Columbia	0
Florida	3,263
Georgia	997
Hawaii	396
Idaho	1,788
Illinois	19,593
Indiana	8,976
Iowa	23,590
Kansas	7,614
Kentucky	1,722
Louisiana	4,335
Maine	0
Maryland	584
Massachusetts	0
Michigan	3,586
Minnesota	14,231
Mississippi	2,191
Missouri	6,007
Montana	1,560
Nebraska	10,931
Nevada	4
New Hampshire	0
New Jersey	91
New Mexico	168
New York	507
North Carolina	1,494
North Dakota	6,602
Ohio	5,001
Oklahoma	1,641
Oregon	567
Pennsylvania	810
Rhode Island	0
South Carolina	331
South Dakota	5,140
Tennessee	1,501
Texas	6,089

Utah	88
Vermont	0
Virginia	502
Washington	1,746
West Virginia	32
Wisconsin	4,419
Wyoming	106
U.S. Total	**157,194**

Methane Emissions from Manure Management

In manure management systems, methane is produced by the anaerobic decomposition of organic matter. The type of manure management system employed determines the extent to which this process occurs. Types of systems included in the EPA State Workbook[3] are pastures, deep pits, liquid slurry, and anaerobic lagoons. Generally speaking, liquid manure management systems, such as ponds, anaerobic lagoons, and holding tanks promote methane production. Manure deposited on fields and pastures, or otherwise handled in a dry form, produces insignificant amounts of methane.

For the purpose of this analysis we included the following animal types: dairy cows, beef cows, hogs and pigs, sheep, chickens (layers and broilers), and turkey. The data on animal population by county was obtained from the 2002 USDA National Agricultural Statistics. All emissions were calculated by animal type and manure management system. The results of these calculations are shown in Figure 12 followed by Table 2 with estimates summarized by state. Please refer to the Analysis Methodology section of this paper for additional information (page 51).

[3] U.S. Environmental Protection Agency, State Workbook: Methodologies for Estimating Greenhouse Gas Emissions, Second Edition, 1995, Workbook 7 Methane Emissions from Manure Management.

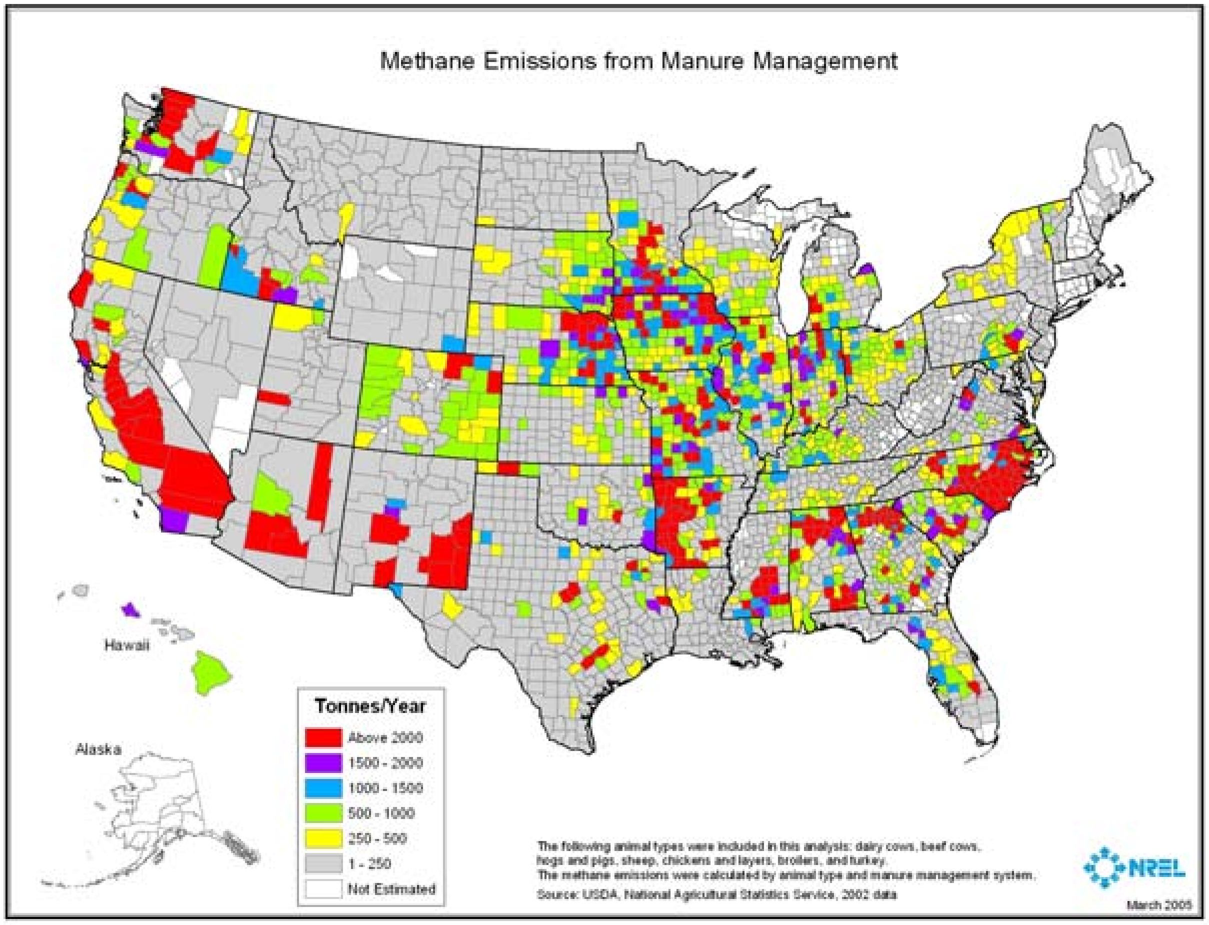

Figure 12 Estimated Methane Emissions from Manure Management by County

Table 2 Estimated Methane Emissions from Manure Management by State

State	Methane (Thousand Tonnes)
Alabama	94
Alaska	0
Arizona	14
Arkansas	145
California	142
Colorado	28
Connecticut	0
Delaware	0.5

District of Columbia	0
Florida	19
Georgia	139
Hawaii	3
Idaho	31
Illinois	76
Indiana	77
Iowa	142
Kansas	22
Kentucky	34
Louisiana	6
Maine	0.2
Maryland	6
Massachusetts	0.1
Michigan	30
Minnesota	71
Mississippi	72
Missouri	120
Montana	4
Nebraska	102
Nevada	0.4
New Hampshire	0
New Jersey	0.3
New Mexico	60
New York	10
North Carolina	370
North Dakota	4
Ohio	41
Oklahoma	47
Oregon	17
Pennsylvania	23
Rhode Island	0
South Carolina	30
South Dakota	36
Tennessee	20
Texas	58

Utah	10
Vermont	3
Virginia	23
Washington	39
West Virginia	1
Wisconsin	19
Wyoming	2
U.S. Total	**2,189**

Wood Residues

Forest Residues

Forest residue data by county was derived from the USDA Forest Service's Timber Product Output database for 2002. In this category we included logging residues and other removals. Logging residues are the unused portions of trees cut, or killed by logging, and left in the woods. Other removals are considered trees cut or otherwise killed by cultural operations (e.g. pre-commercial thinning, weeding, etc.) or land clearings and forest uses that are not directly associated with round wood product harvests. It does not include volume removed from the inventory by reclassification of timberland to productive reserved forestland[4]. The results of this analysis are visualized in Figure 13, and Table 3 shows the summary by state. The Analysis Methodology section of this paper describes the methodology used (page 51).

[4] U.S. Department of Agriculture, Forest Service, Forest Inventory and Analysis, Timber Product Output Database Retrieval System

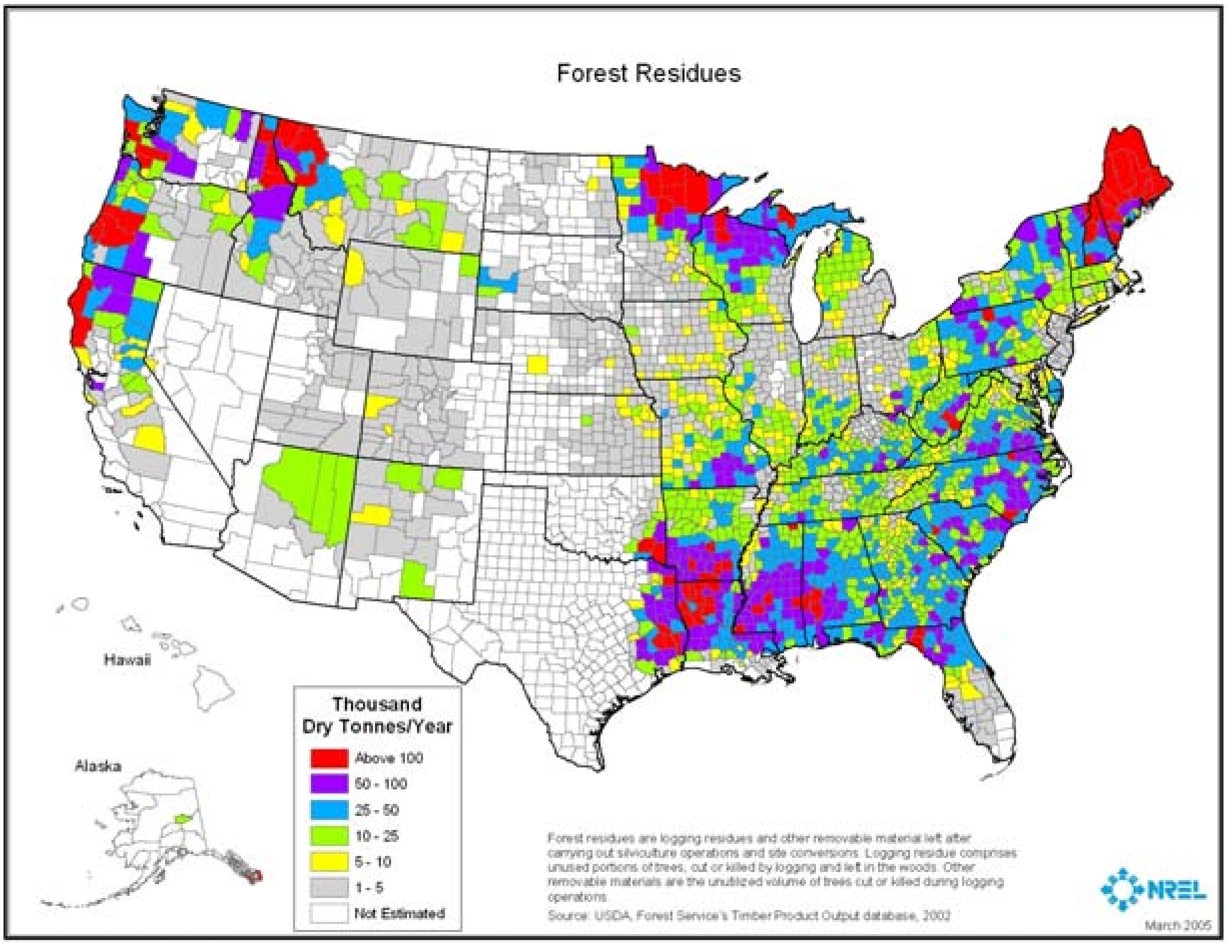

Figure 13 Estimated Forest Residues by County

Table 3 Estimated Forest Residues by State

State	Forest Residues (Thousand Dry Tonnes)
Alabama	2,555
Alaska	738
Arizona	59
Arkansas	2,874
California	1,303
Colorado	70
Connecticut	78
Delaware	51

District of Columbia	0
Florida	1,778
Georgia	3,556
Hawaii	0
Idaho	873
Illinois	664
Indiana	863
Iowa	359
Kansas	134
Kentucky	2,055
Louisiana	3,384
Maine	2,890
Maryland	263
Massachusetts	89
Michigan	1,275
Minnesota	2,242
Mississippi	3,825
Missouri	1,840
Montana	704
Nebraska	72
Nevada	5
New Hampshire	986
New Jersey	29
New Mexico	71
New York	1,111
North Carolina	2,995
North Dakota	27
Ohio	796
Oklahoma	655
Oregon	1,041
Pennsylvania	1,679
Rhode Island	8
South Carolina	1,733
South Dakota	125
Tennessee	1,319
Texas	2,060

Utah	30
Vermont	496
Virginia	2,403
Washington	1,034
West Virginia	1,347
Wisconsin	2,011
Wyoming	58
U.S. Total	**56,612**

Primary Mill Residues

Primary mill residue data by county was derived from the USDA Forest Service's Timber Product Output database for 2002. Primary mill residues are composed of wood materials (coarse and fine) and bark generated at manufacturing plants (primary wood-using mills) when round wood products are processed into primary wood products, like slabs, edgings, trimmings, sawdust, veneer clippings and cores, and pulp screenings. It includes mill residues recycled as byproducts as well as those left un-utilized and disposed of as waste[5]. Figure 14 shows the primary mill residues recycled as byproducts (fuel or fiber) as well as those left un-utilized and disposed of as waste. Figure 15 depicts mill residues not being used for any byproduct. This includes mill residues burned as waste or landfilled. Table 4 illustrates the results by state. Refer to the Analysis Methodology section of this paper for more information on the applied methodology (page 51).

[5] U.S. Department of Agriculture, Forest Service, Forest Inventory and Analysis, Timber Product Output Database Retrieval System

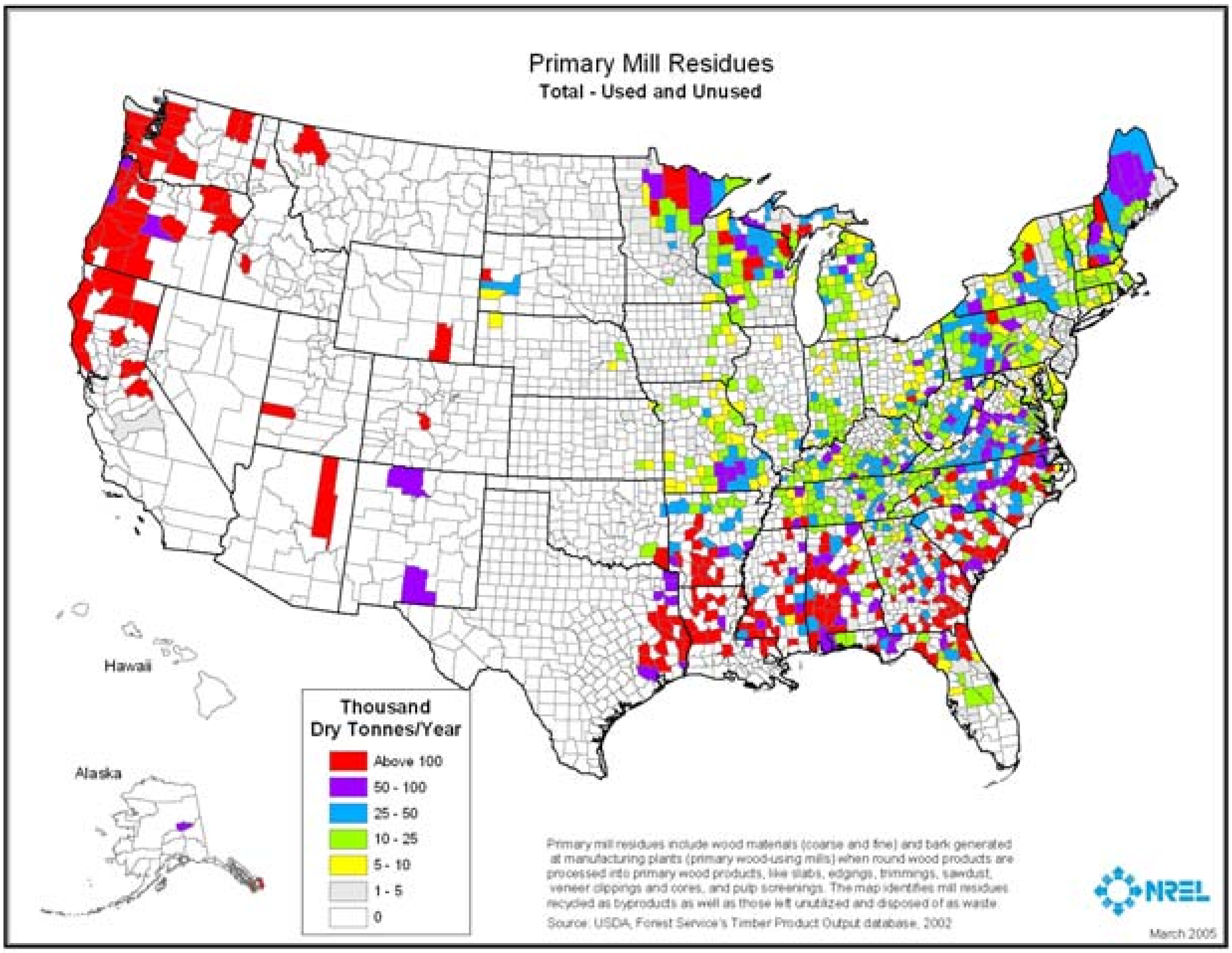

Figure 14 Estimated Total Primary Mill Residues (Used and Unused) by County

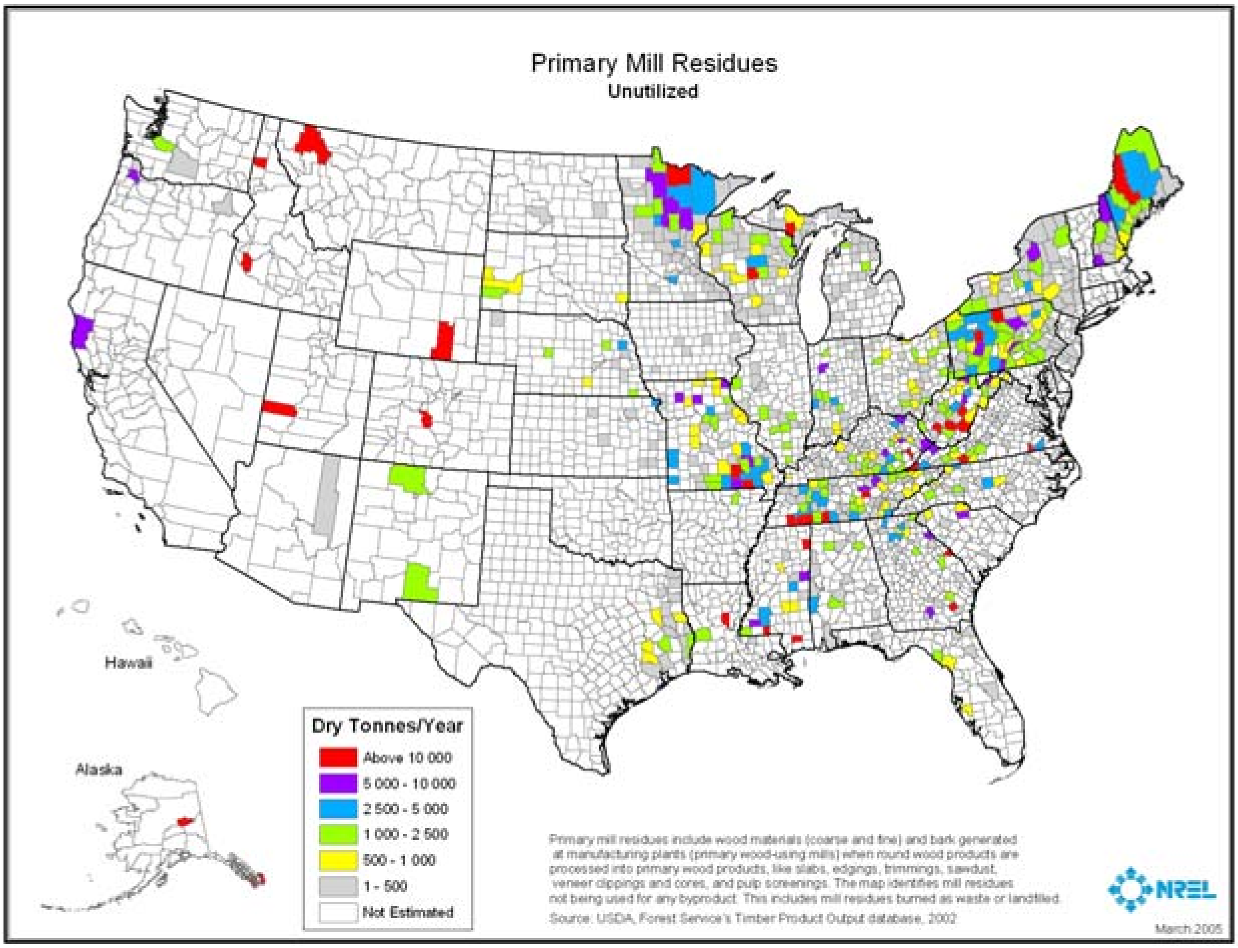

Figure 15 Estimated Unutilized Primary Mill Residues by County

Table 4 Estimated Primary Mill Residues by State (Thousand Dry Tonnes)

State	Total	Unused
Alabama	5,857	10
Alaska	231	131
Arizona	109	0.2
Arkansas	3,623	2
California	4,772	8
Colorado	181	87
Connecticut	75	0
Delaware	14	0.05
District of Columbia	0	0
Florida	1,901	4

Georgia	7,231	66
Hawaii	0	0
Idaho	4,400	69
Illinois	233	14
Indiana	574	26
Iowa	130	2
Kansas	29	5
Kentucky	1,433	77
Louisiana	3,577	14
Maine	421	35
Maryland	138	0.2
Massachusetts	113	0
Michigan	1,314	41
Minnesota	985	65
Mississippi	4,548	79
Missouri	1,036	130
Montana	1,937	41
Nebraska	57	9
Nevada	0	0
New Hampshire	925	19
New Jersey	17	0.2
New Mexico	165	4
New York	1,063	24
North Carolina	3,900	14
North Dakota	0	0.2
Ohio	786	18
Oklahoma	633	0
Oregon	6,454	9
Pennsylvania	1,358	144
Rhode Island	21	0
South Carolina	2,468	9
South Dakota	142	5
Tennessee	1,557	153
Texas	2,085	8
Utah	102	20
Vermont	103	0

Virginia	2,147	66
Washington	5,597	6
West Virginia	807	114
Wisconsin	1,621	30
Wyoming	255	47
U.S. Total	**77,125**	**1,606**

Secondary Mill Residues

Secondary mill residues include wood scraps and sawdust from woodworking shops—furniture factories, wood container and pallet mills, and wholesale lumberyards. The following business categories were included in this analysis:

- Furniture factories: wood kitchen cabinet and countertop, non upholstered wood household furniture, wood office furniture, custom architectural woodwork and millwork, and wood window and door manufacturers
- Millwork: cut stock, re sawing lumber and planning, and other millwork (including flooring)
- Truss manufacturing
- Wood container and pallet manufacturing
- Lumber, plywood, millwork and wood panel wholesale companies

Data on the number of businesses by county was gathered from the U.S. Census Bureau, 2002 County Business Patterns. Depending on the size of a company (number of employees) and assumptions on the wood waste generated by a company derived from Wiltsee's study[6], the results of this analysis are shown in Figure 16 and Table 5. According to this study, pallet and lumber companies generate about 300 tons/year, and a small woodworking company typically generates between 5 and 20 tons/year of wood waste.

[6] Wiltsee, G, Urban Wood Waste Resource Assessment, Appel Consultant, Inc. Valencia, CA. November, 1998.

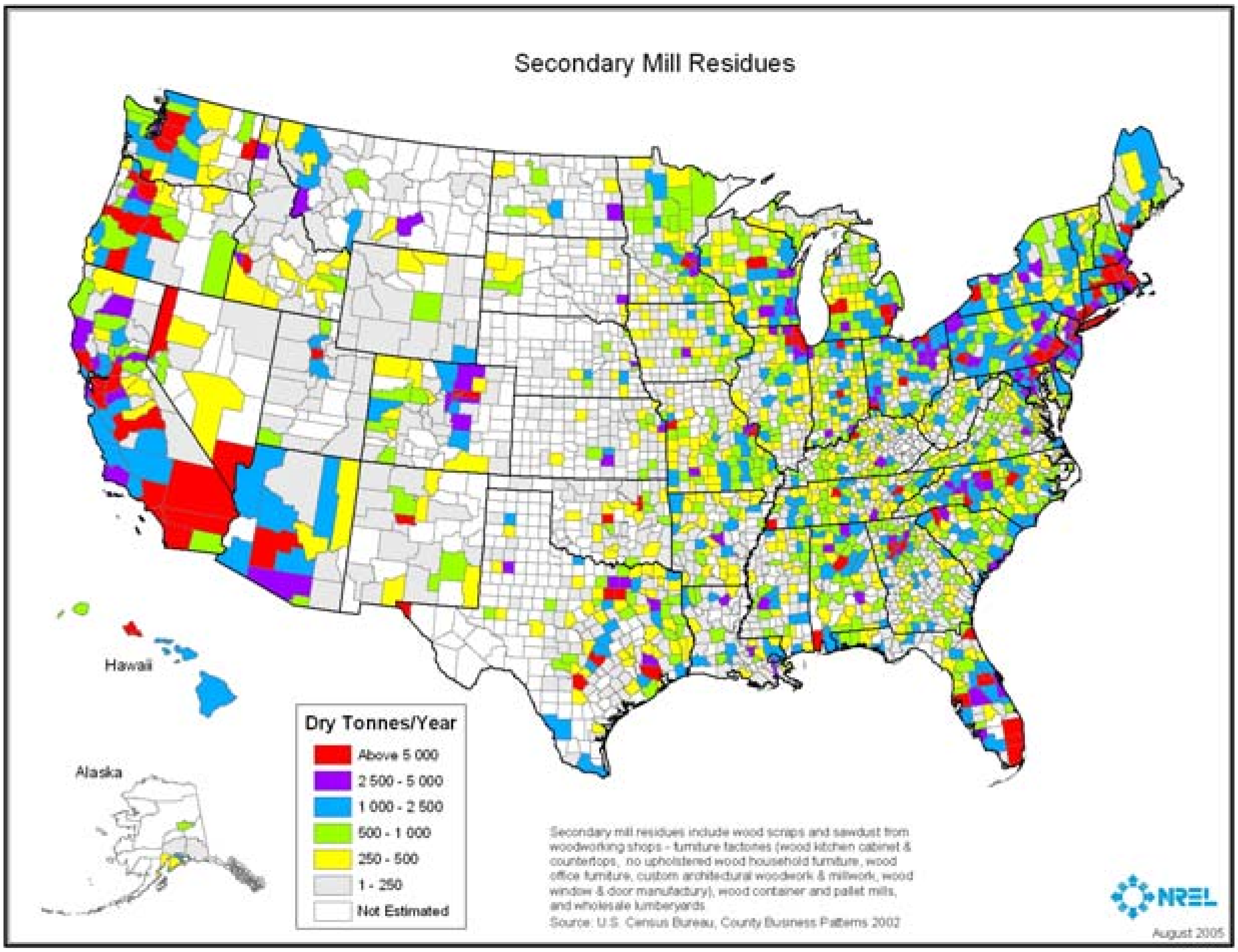

Figure 16 Estimated Secondary Mill Residues by County

Table 5 Estimated Secondary Mill Residues by State

State	Secondary Mill Residues (Thousand Dry Tonnes)
Alabama	57
Alaska	2
Arizona	41
Arkansas	32
California	247
Colorado	41
Connecticut	24
Delaware	8
District of Columbia	0
Florida	130

Georgia	97
Hawaii	10
Idaho	20
Illinois	96
Indiana	71
Iowa	29
Kansas	19
Kentucky	52
Louisiana	33
Maine	15
Maryland	33
Massachusetts	52
Michigan	86
Minnesota	59
Mississippi	33
Missouri	69
Montana	13
Nebraska	13
Nevada	17
New Hampshire	18
New Jersey	58
New Mexico	9
New York	119
North Carolina	115
North Dakota	7
Ohio	124
Oklahoma	23
Oregon	86
Pennsylvania	127
Rhode Island	6
South Carolina	38
South Dakota	7
Tennessee	75
Texas	148
Utah	18
Vermont	9

Virginia	62
Washington	85
West Virginia	15
Wisconsin	69
Wyoming	4
U.S. Total	**2,615**

Urban Wood Residues

Three major categories of urban wood residues were considered in this study:

- MSW wood—wood chips, pallets, and yard waste
- Utility tree trimming and/or private tree companies
- Construction/demolition wood

Data on the collected urban wood waste are not available; thus numerous assumptions were applied for estimation. Please, refer to the Analysis Methodology section of this paper for more information (page 51). The results of this analysis are shown on Figure 17 and Table 6.

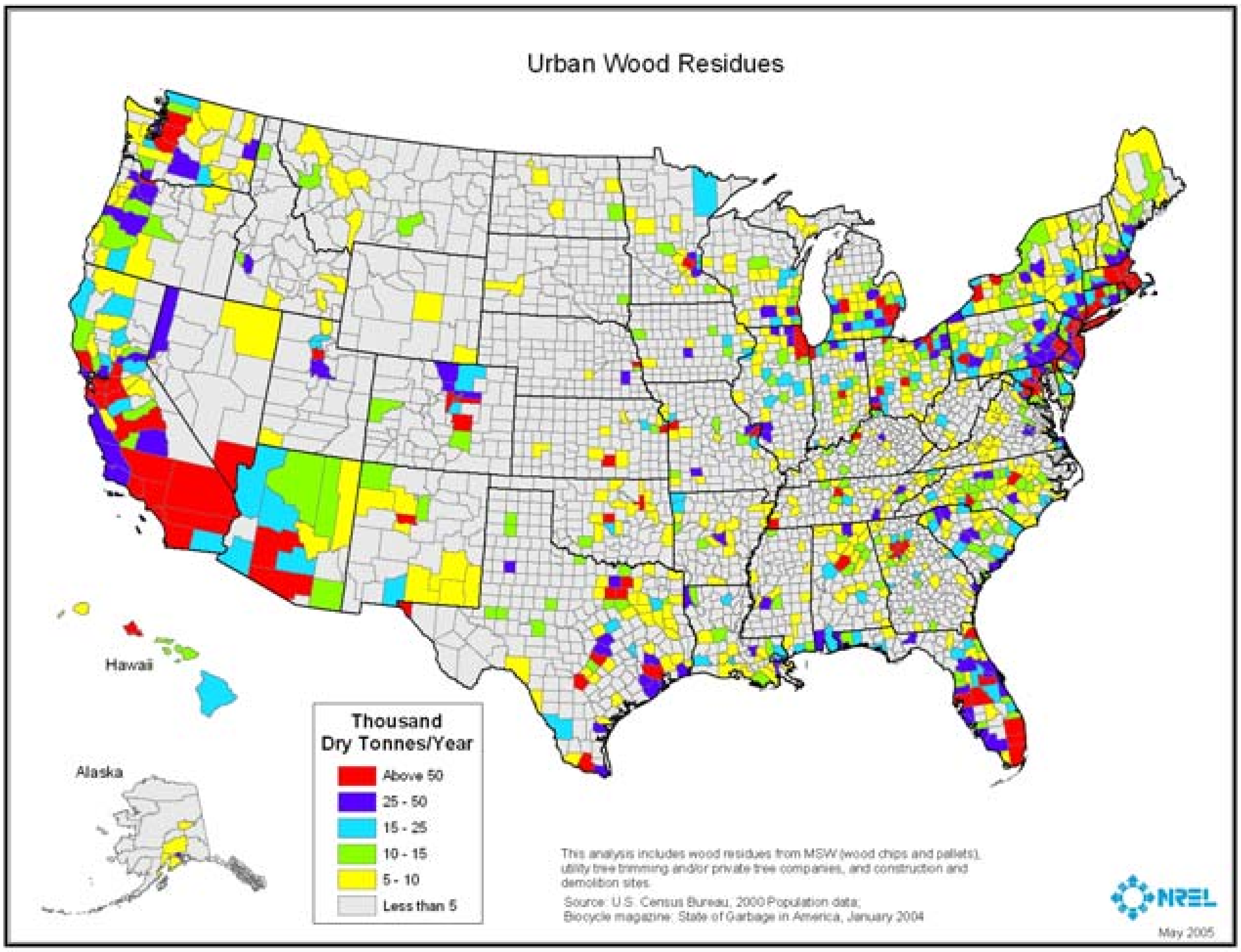

Figure 17 Estimated Urban Wood Residues by County

Table 6 Estimated Urban Wood Residues by State

State	Urban Wood Residues (Thousand Dry Tonnes)
Alabama	483
Alaska	65
Arizona	526
Arkansas	314
California	3,901
Colorado	451
Connecticut	376
Delaware	85
District of Columbia	56

Florida	1,678
Georgia	924
Hawaii	133
Idaho	129
Illinois	1,337
Indiana	715
Iowa	320
Kansas	332
Kentucky	454
Louisiana	474
Maine	133
Maryland	624
Massachusetts	687
Michigan	1,196
Minnesota	496
Mississippi	307
Missouri	613
Montana	106
Nebraska	189
Nevada	232
New Hampshire	126
New Jersey	894
New Mexico	191
New York	2,041
North Carolina	833
North Dakota	67
Ohio	1,272
Oklahoma	377
Oregon	382
Pennsylvania	1,238
Rhode Island	109
South Carolina	467
South Dakota	75
Tennessee	614
Texas	2,307
Utah	228

Vermont	65
Virginia	813
Washington	675
West Virginia	184
Wisconsin	548
Wyoming	59
U.S. Total	**30,902**

Municipal Discards

Methane Emissions from Landfills

The methane emissions from landfills depend on three key factors: (1) total waste in place; (2) landfill size; and (3) location in an arid or non-arid climate. Data on the landfill locations and the waste in place was obtained from EPA's Landfill Methane Outreach Program (LMOP), 2003 database. For this study we used the landfill size defined by EPA. A large landfill is one containing more than 1.1 million tons of waste in place. With regard to moisture as a factor in the methane production, landfills in non-arid climates are believed to produce more methane per unit of waste in place than do landfills in arid climates. Therefore different methane emission estimates have been developed for non-arid states and for arid states.

The methane emissions from landfills were summed by county, and the map shown in Figure 18 was generated. Details on the methodology used are described in the Analysis Methodology section of this paper (page 51).

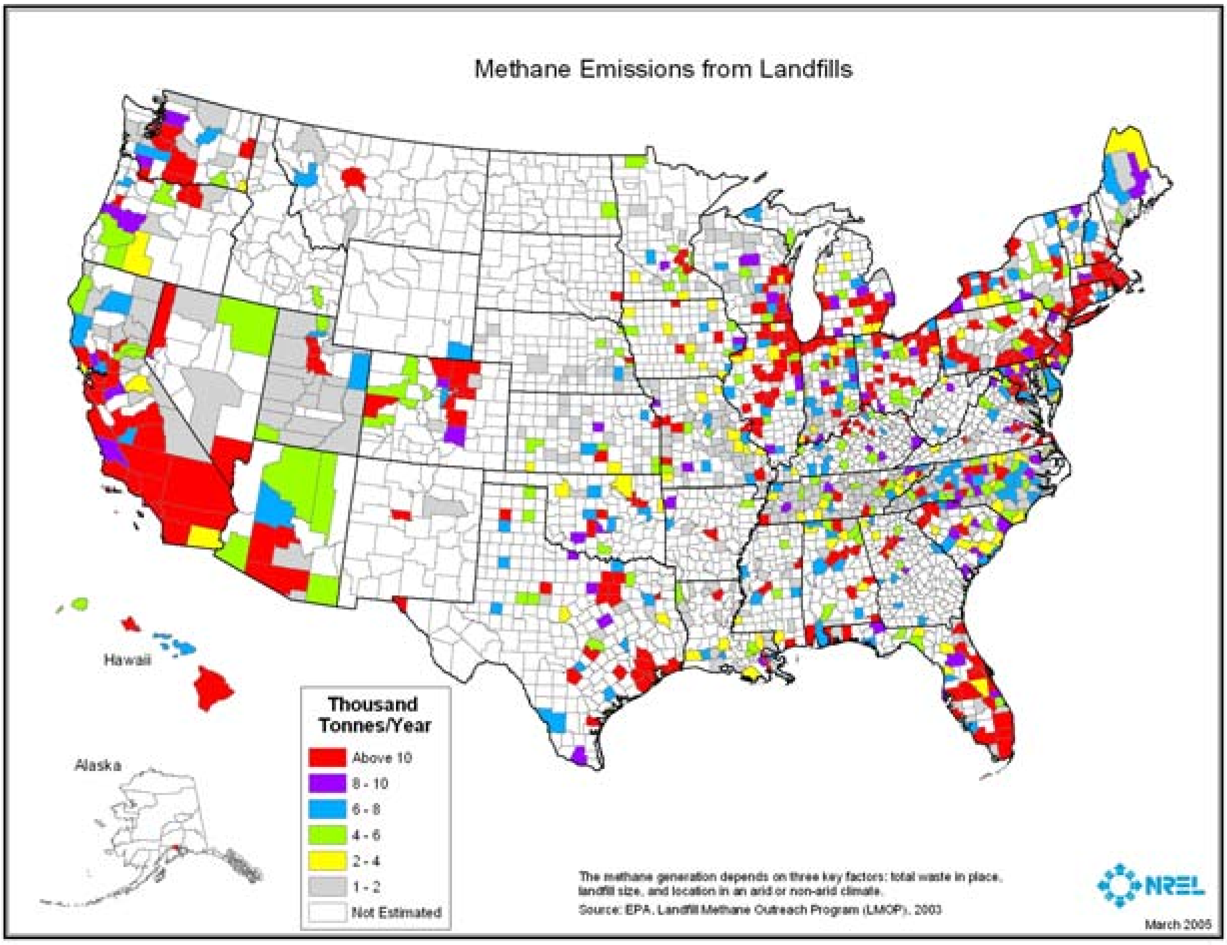

Figure 18 Estimated Methane Emissions from Landfills

Table 7 Estimated Methane Emissions from Landfills by State

State	Methane (Thousand Tonnes)
Alabama	236
Alaska	11
Arizona	151
Arkansas	38
California	1,359
Colorado	273
Connecticut	66
Delaware	58

District of Columbia	0
Florida	457
Georgia	201
Hawaii	58
Idaho	7
Illinois	974
Indiana	526
Iowa	137
Kansas	139
Kentucky	250
Louisiana	166
Maine	27
Maryland	204
Massachusetts	206
Michigan	446
Minnesota	148
Mississippi	93
Missouri	273
Montana	21
Nebraska	48
Nevada	76
New Hampshire	40
New Jersey	497
New Mexico	31
New York	885
North Carolina	427
North Dakota	5
Ohio	647
Oklahoma	153
Oregon	125
Pennsylvania	642
Rhode Island	28
South Carolina	181
South Dakota	10
Tennessee	274
Texas	845

Utah	76
Vermont	21
Virginia	275
Washington	240
West Virginia	47
Wisconsin	273
Wyoming	8
U.S. Total	**12,380**

Methane Emissions from Domestic Wastewater Treatment

The total methane emissions from wastewater treatment are insignificant compared with other biomass resources; however they may be of importance locally when, by reusing the methane within the facility, a region can reduce greenhouse gas emissions and keep electricity costs low.

The treatment process of wastewater from domestic sources (municipal sewage) and industrial sources (pulp and paper; meat and poultry processing; and vegetables, fruits and juices processing) under anaerobic conditions (i.e., without oxygen) results in methane emissions. This study estimates the methane emissions from domestic sources using the methodology from the EPA Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2003, described on page 51 of this paper. According to the Department of Energy's Federal Energy Management Program (FEMP) about 3,500 of the 16,000 wastewater treatment plants (domestic and industrial) currently employ anaerobic digestion. The results are displayed in Figure 19 and Table 8.

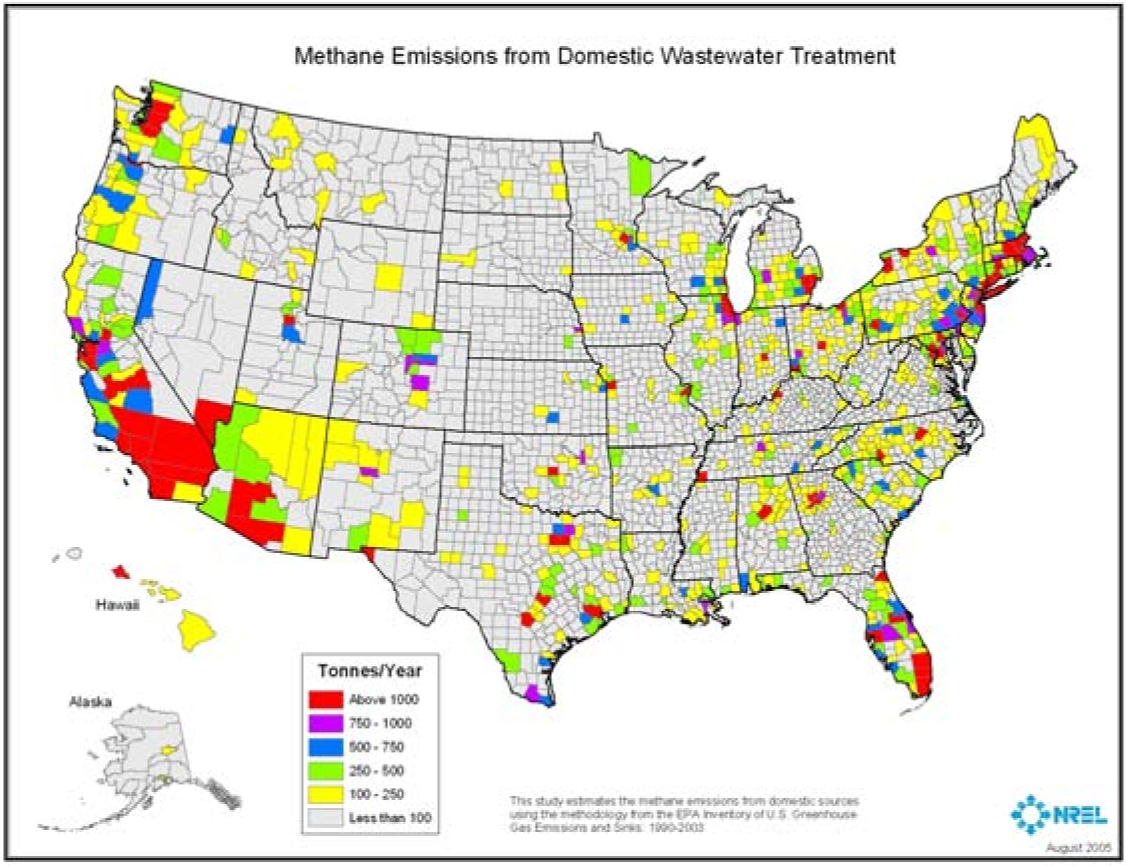

Figure 19 Estimated Methane Emissions from Domestic Wastewater Treatment by County

Table 8 Estimated Methane Emissions from Domestic Wastewater Treatment by State

State	Methane (Thousand Tonnes)
Alabama	7
Alaska	1
Arizona	8
Arkansas	4
California	56
Colorado	7
Connecticut	6
Delaware	1
District of Columbia	1
Florida	26
Georgia	14
Hawaii	2
Idaho	2

Illinois	21
Indiana	10
Iowa	5
Kansas	4
Kentucky	7
Louisiana	7
Maine	2
Maryland	9
Massachusetts	10
Michigan	16
Minnesota	8
Mississippi	5
Missouri	9
Montana	1
Nebraska	3
Nevada	3
New Hampshire	2
New Jersey	14
New Mexico	3
New York	31
North Carolina	13
North Dakota	1
Ohio	19
Oklahoma	6
Oregon	6
Pennsylvania	20
Rhode Island	2
South Carolina	7
South Dakota	1
Tennessee	9
Texas	34
Utah	4
Vermont	1
Virginia	12
Washington	10
West Virginia	3
Wisconsin	9
Wyoming	1
U.S. Total	465

Dedicated Energy Crops Case Studies

Conservation Reserve Program (CRP) Lands

Dedicated energy crops (switch grass, willow, hybrid poplar, etc.) can often be economically grown on land that is not suitable for conventional crops and can provide erosion protection for agricultural set aside or CRP lands. The CRP is a voluntary program for agricultural landowners, and is administered by the USDA Farm Service Agency. It provides technical and financial assistance to eligible farmers and ranchers to address soil, water, and other related natural resource concerns on their lands. Data on the CRP acres by county were obtained from the USDA's Farm Service Agency and the map on Figure 20 was generated. The amount of energy crops that could be potentially grown on these lands is shown on Figure 21 and 22. More information on the used methodology is provided in the Analysis Methodology section of this paper (page 51).

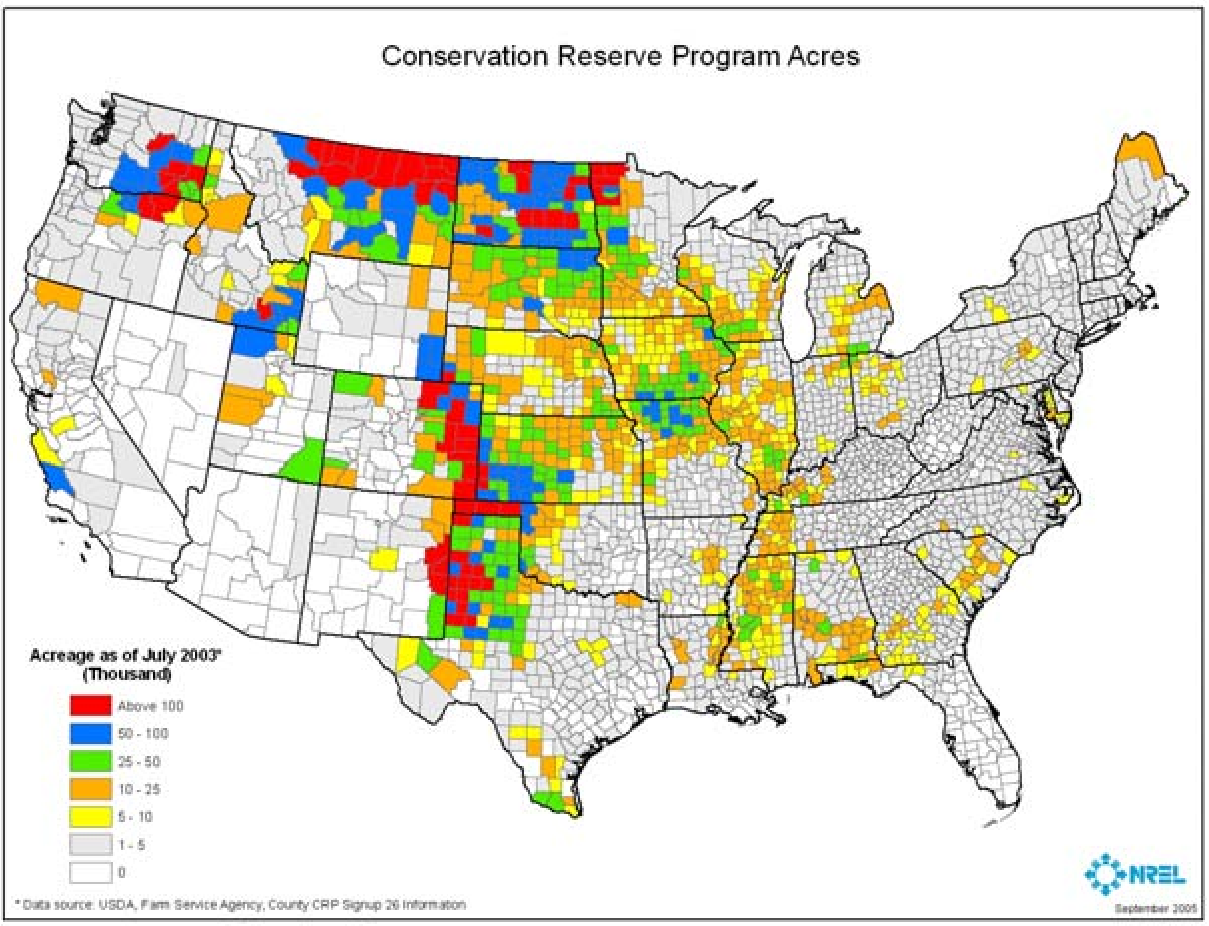

Figure 20 Conservation Reserve Program Acres by County

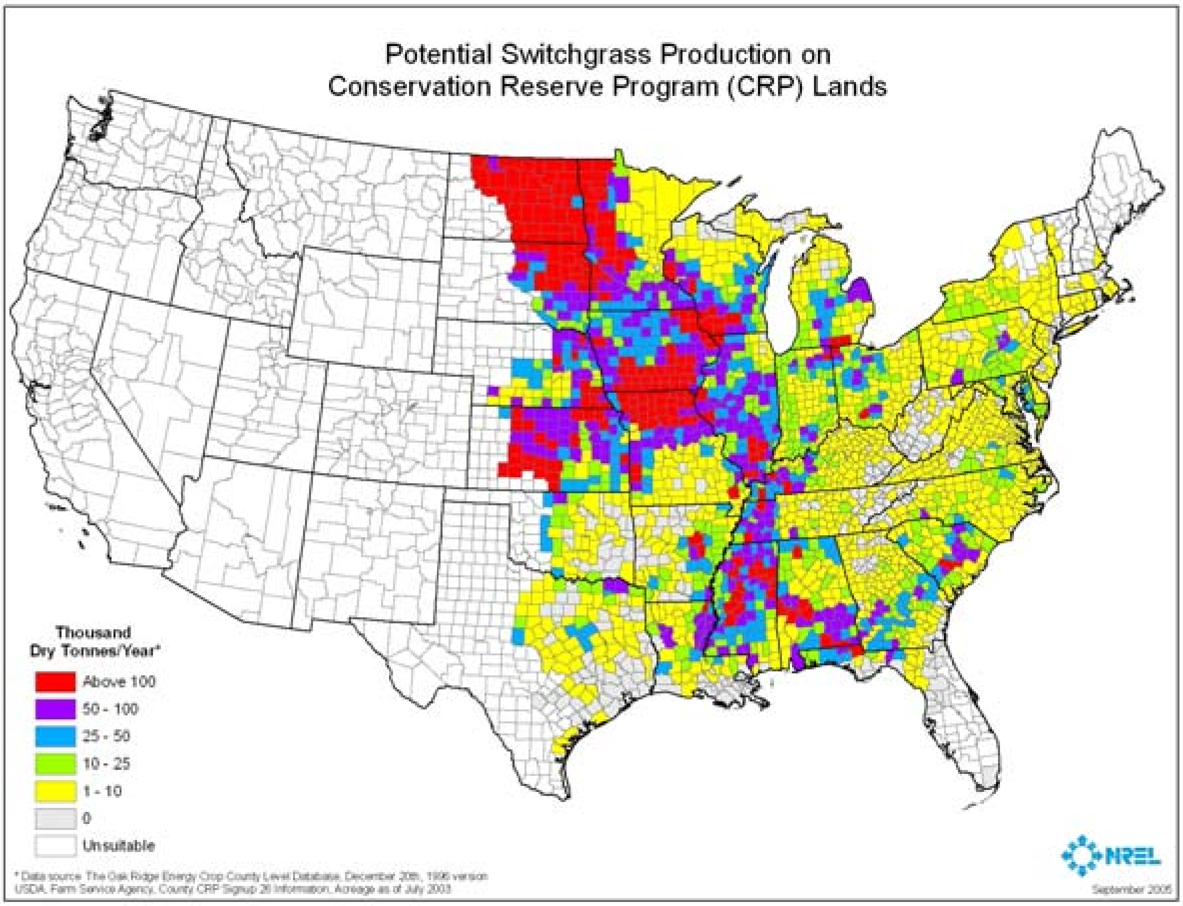

Figure 21 Potential Switchgrass Production on CRP Lands

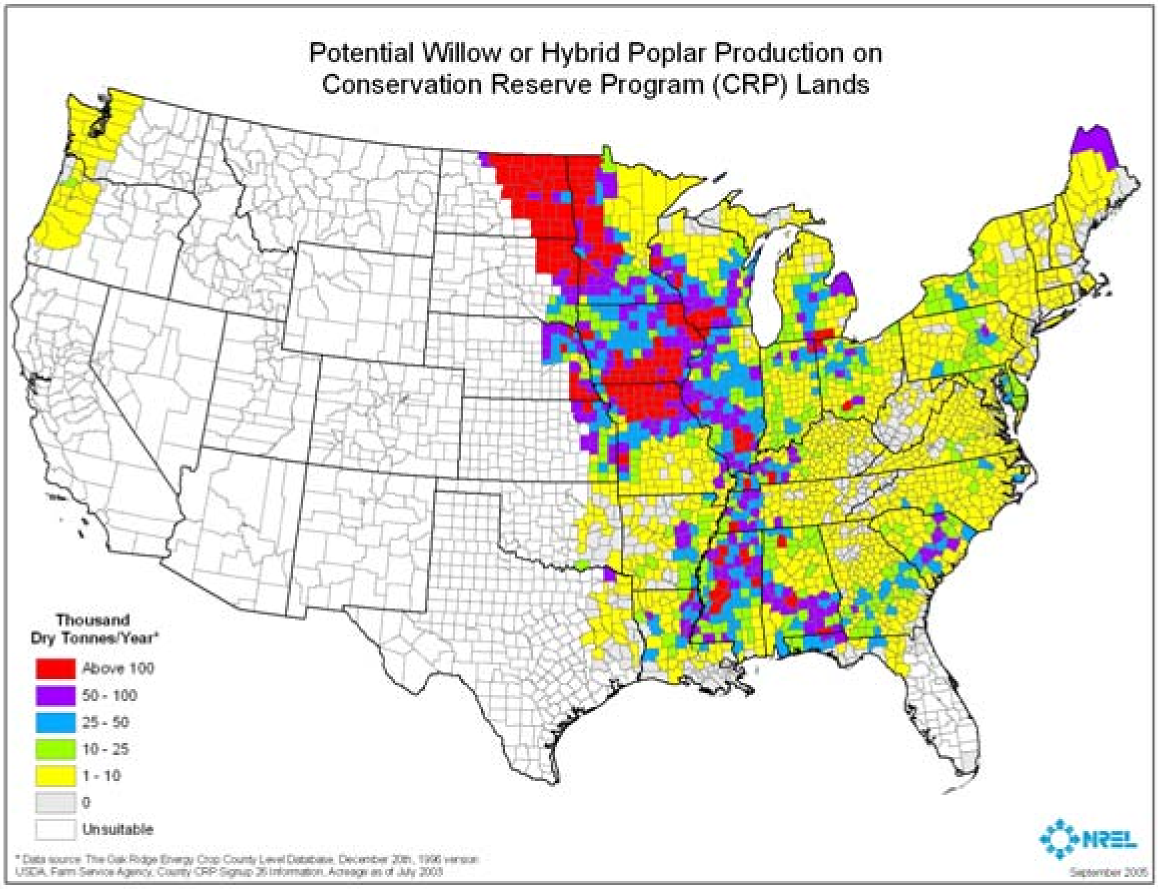

Figure 22 Potential Willow or Hybrid Poplar Production on CRP Lands

Table 9 Potential Energy Crops Production (Thousand Dry Tonnes/Year) on CRP Lands by State

State	Switchgrass	Willow or Hybrid Poplar
Alabama	2,660	1,968
Alaska	0	0
Arizona	0	0
Arkansas	951	727
California	0	0
Colorado	0	0
Connecticut	1	2
Delaware	22	30
District of Columbia	0	0
Florida	460	353
Georgia	1,646	1,238

Hawaii	0	0
Idaho	0	0
Illinois	5,290	4,422
Indiana	1,609	1,348
Iowa	10,249	8,539
Kansas	6,274	1,124
Kentucky	1,822	1,433
Louisiana	1,072	903
Maine	0	77
Maryland	271	319
Massachusetts	0.2	0.5
Michigan	1,451	1,410
Minnesota	7,851	7,230
Mississippi	4,883	3,849
Missouri	8,473	6,926
Montana	0	0
Nebraska	3,344	1,956
Nevada	0	0
New Hampshire	0.04	1
New Jersey	11	10
New Mexico	0	0
New York	264	335
North Carolina	577	440
North Dakota	10,476	6,976
Ohio	1,587	1,337
Oklahoma	407	28
Oregon	0	32
Pennsylvania	672	556
Rhode Island	0	0
South Carolina	1,061	861
South Dakota	4,807	2,565
Tennessee	1,375	1,088
Texas	569	84
Utah	0	0
Vermont	4	6
Virginia	297	212

Washington	0	15
West Virginia	9	7
Wisconsin	3,126	2,912
Wyoming	0	0
U.S. Total	**83,572**	**61,323**

Abandoned Mine Lands

Another potential use of energy crops is on environmentally damaged lands, such as closed mining sites. Data regarding the acreage of these mines is difficult to find, therefore it is hard to calculate the energy crops that could be produced on these sites. Figure 23 and Figure 24 display only their locations over the estimated yield of energy crops by county in the hope that this work brings a proposed solution for thousands of acres now largely considered wastelands, and that one day they will return to productive use. An example of a successful project is the pilot "Energy Crop Plantation" of non-invasive eucalyptus and native cottonwood trees established on a closed phosphate mine in Central Florida. At approximately 130 acres (~ 250,000 trees), the tree plantation represents the largest tree biomass energy crop plantation in the United States[7]. More information on the data and methodology used can be found under the Analysis Methodology section of this paper (page 51).

[7] Biomass Energy: A research commitment on Global Warming, Renewable Energy, and Reforestation by using Nature's own "power plants"... Trees!, Planet Power: Energy and the Environment (Hhttp://www.treepower.org/H)

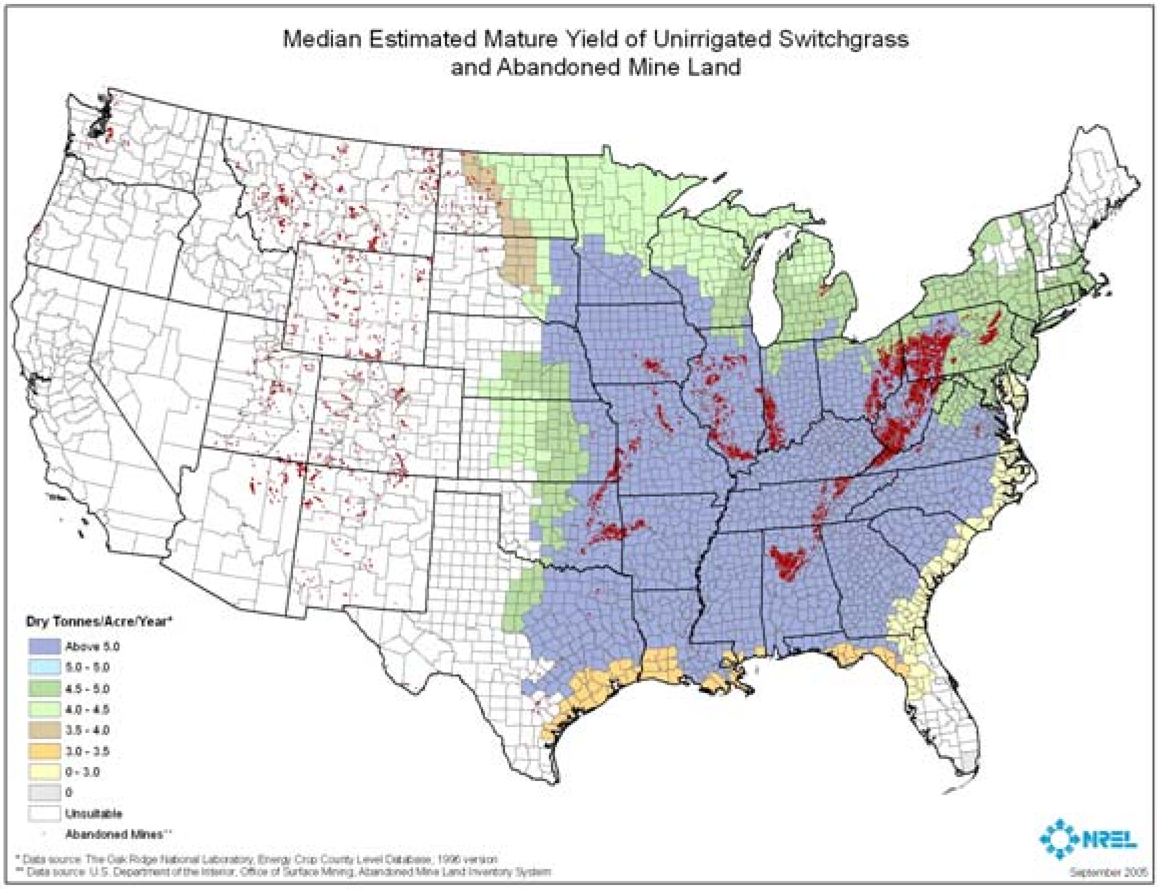

Figure 23 Potential Switchgrass Production and Abandoned Mine Lands

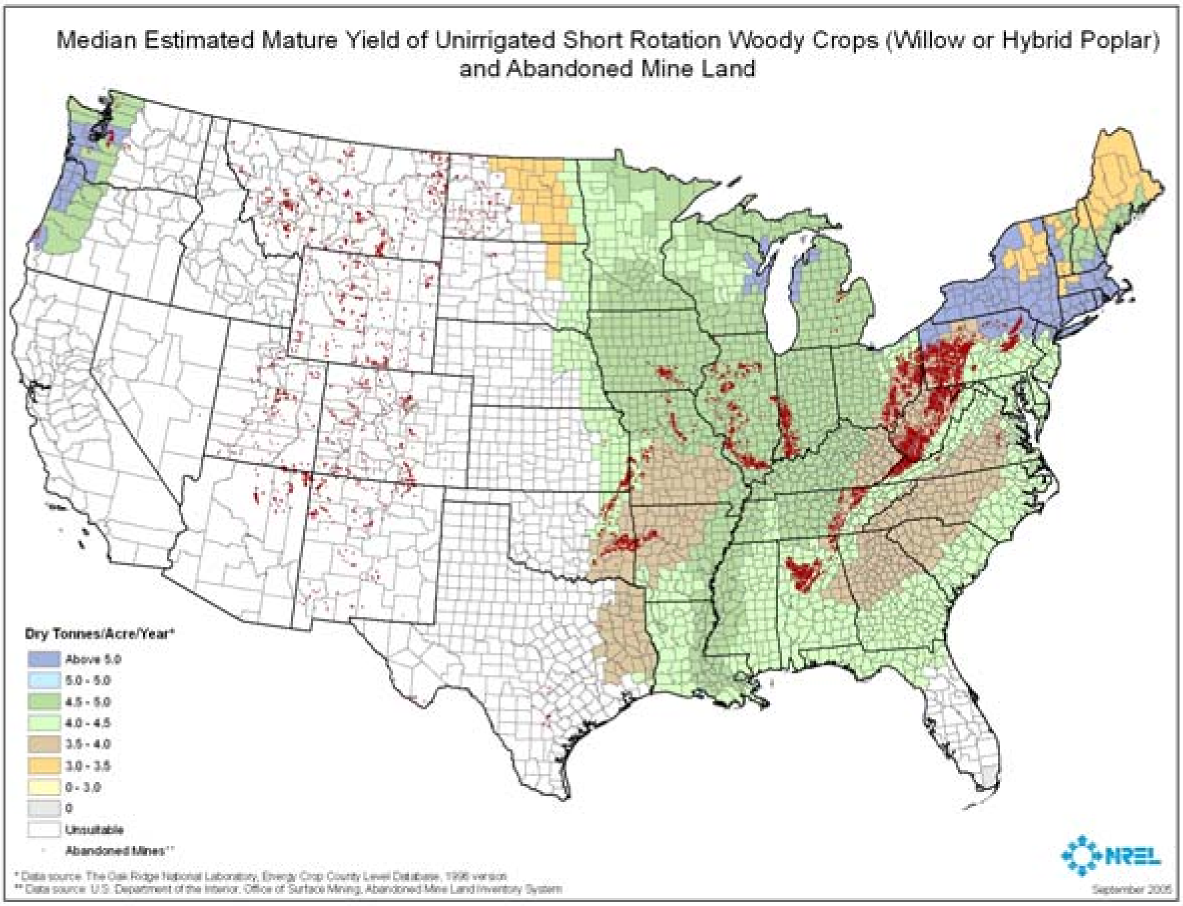

Figure 24 Potential Willow or Hybrid Poplar Production and Abandoned Mine Lands

Summary

This research attempted to estimate the biomass resources currently available in the United States, and to examine their geographic distribution. It also addresses the use of GIS as a powerful method for collecting, exploring, analyzing, and visualizing the biomass data. The results of this study show that an estimated 423 million tonnes of biomass are technically available in the country (Table 10). The geographic pattern of this resource availability by county is shown on Figure 25, and Figure 26 illustrates the numbers normalized by county area. The crop, forest, and primary mill residues provide about 70% of the total biomass resources (Figure 28 and Figure 29). While the resources from other feedstocks are relatively insignificant, they could play an important role at a regional and local level.

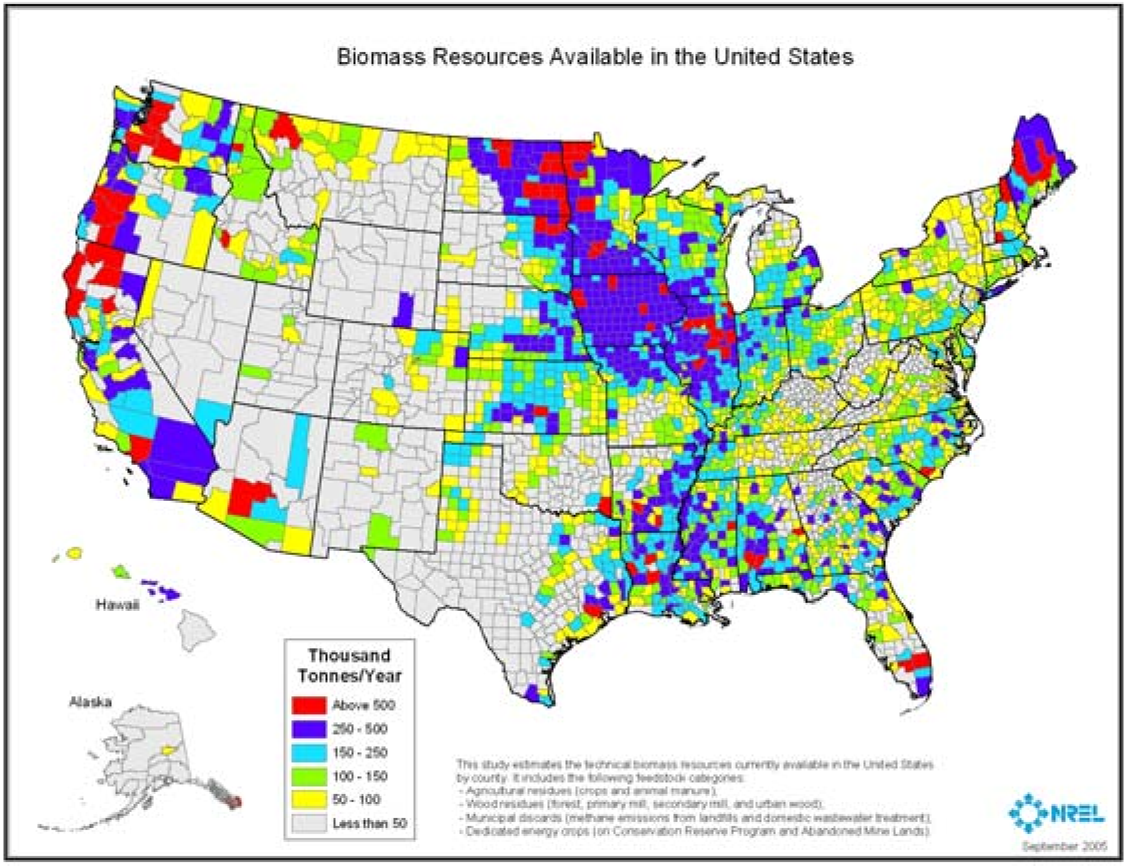

Figure 25 Total Biomass Resources Available in the United States by County

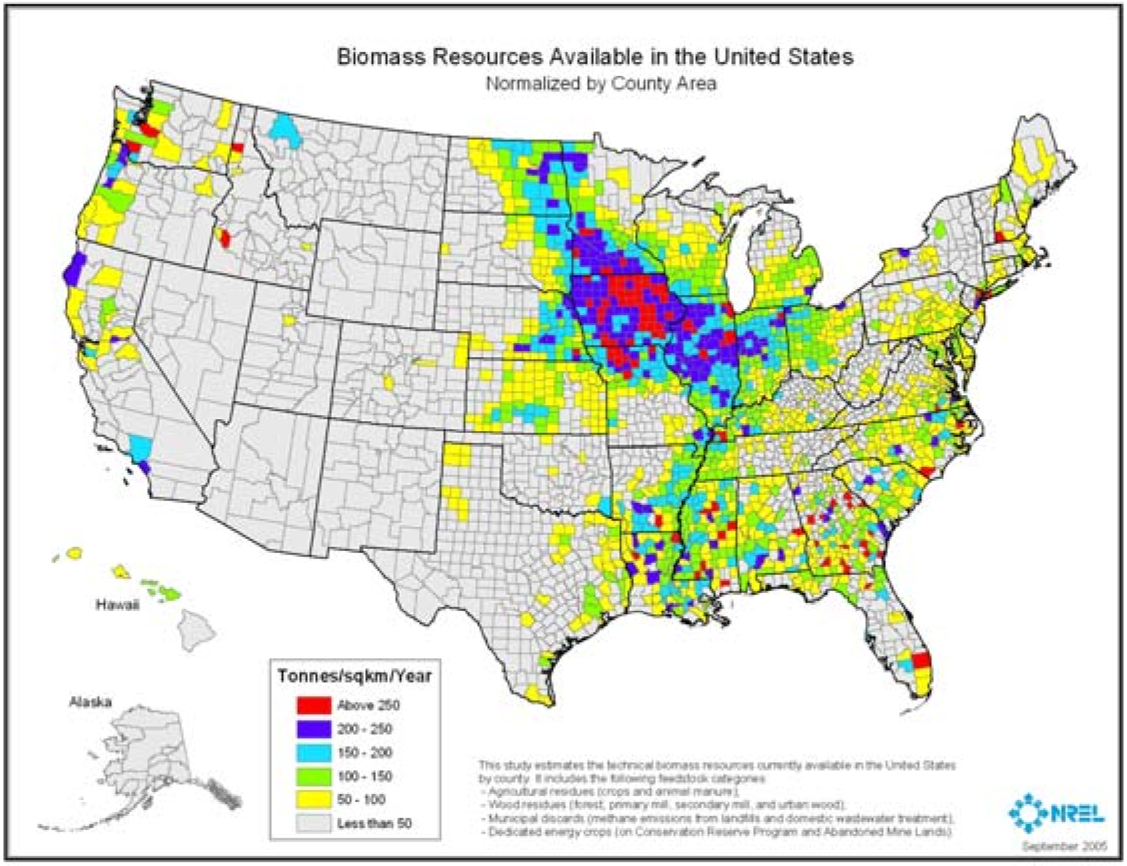

Figure 26 Total Biomass Resources Available in the United States per Square Kilometer by County

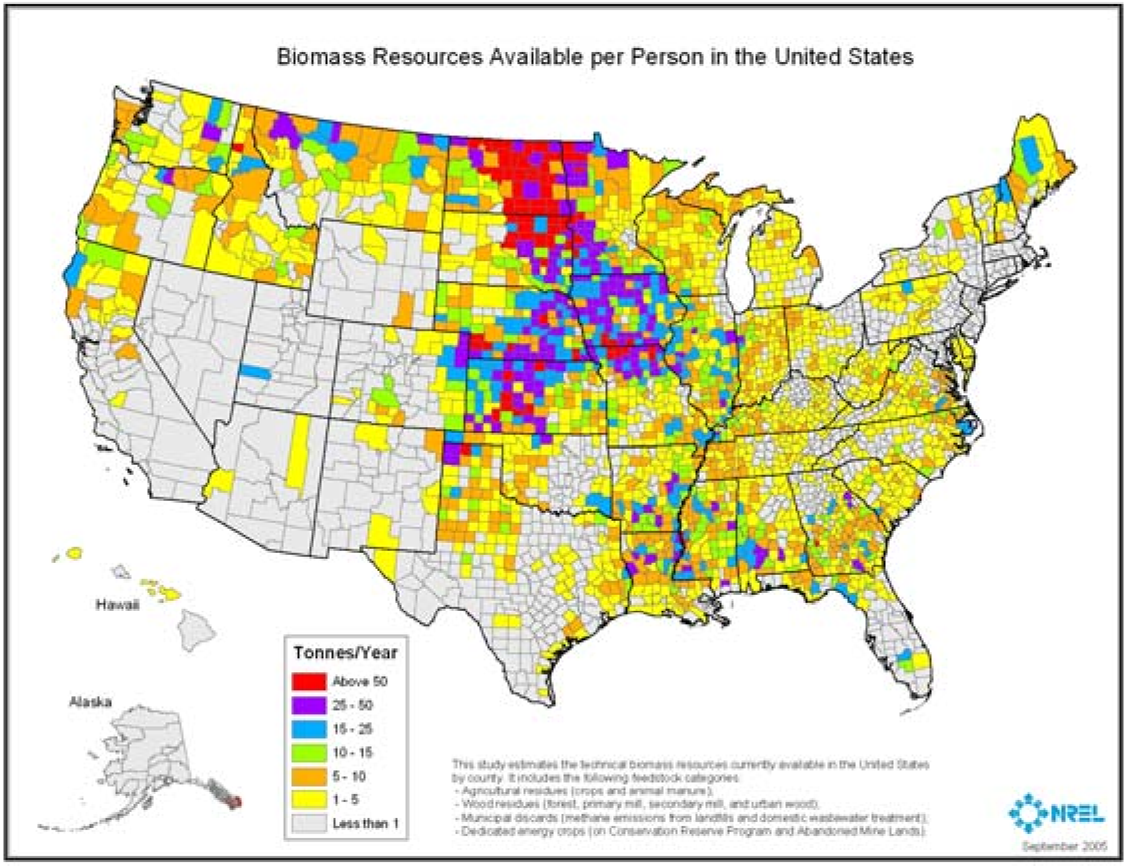

Figure 27 Total Biomass Resources Available per Person in the United States by County

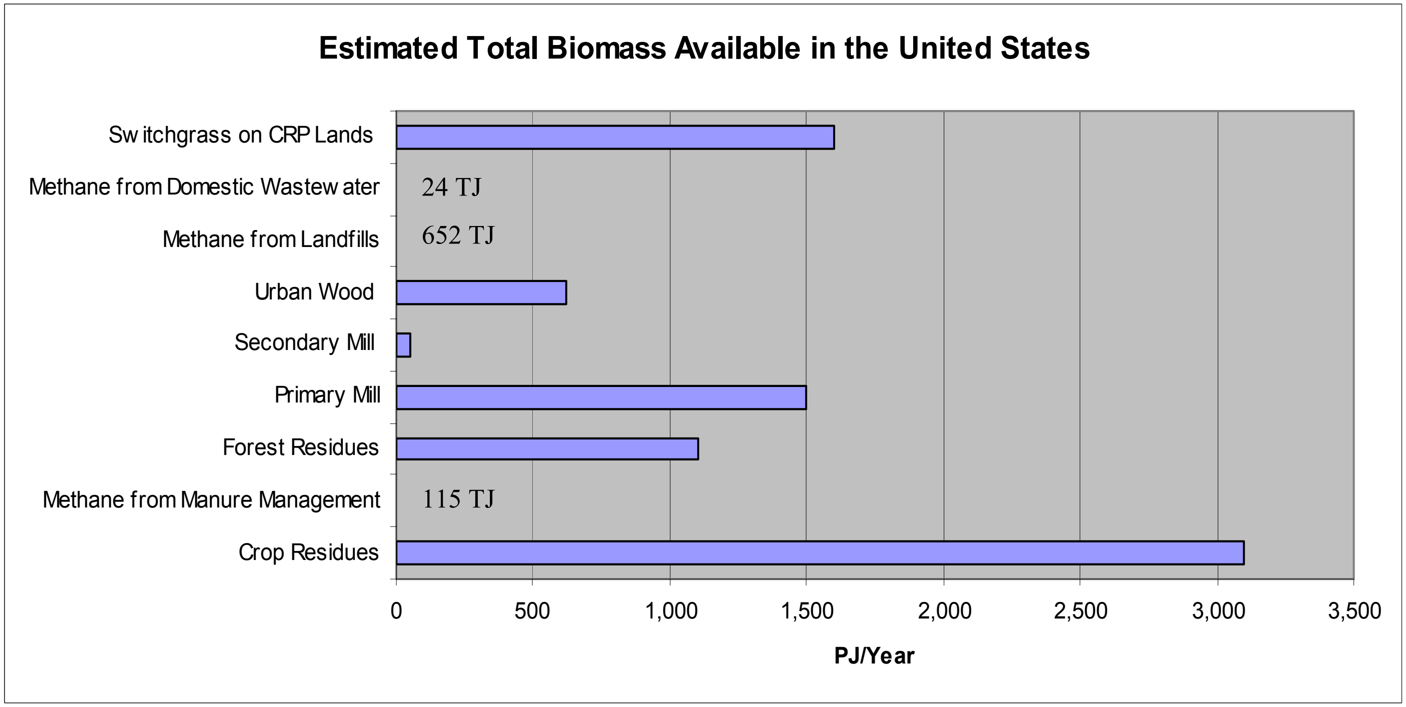

Figure 28 Estimated Total Biomass Available in the United States

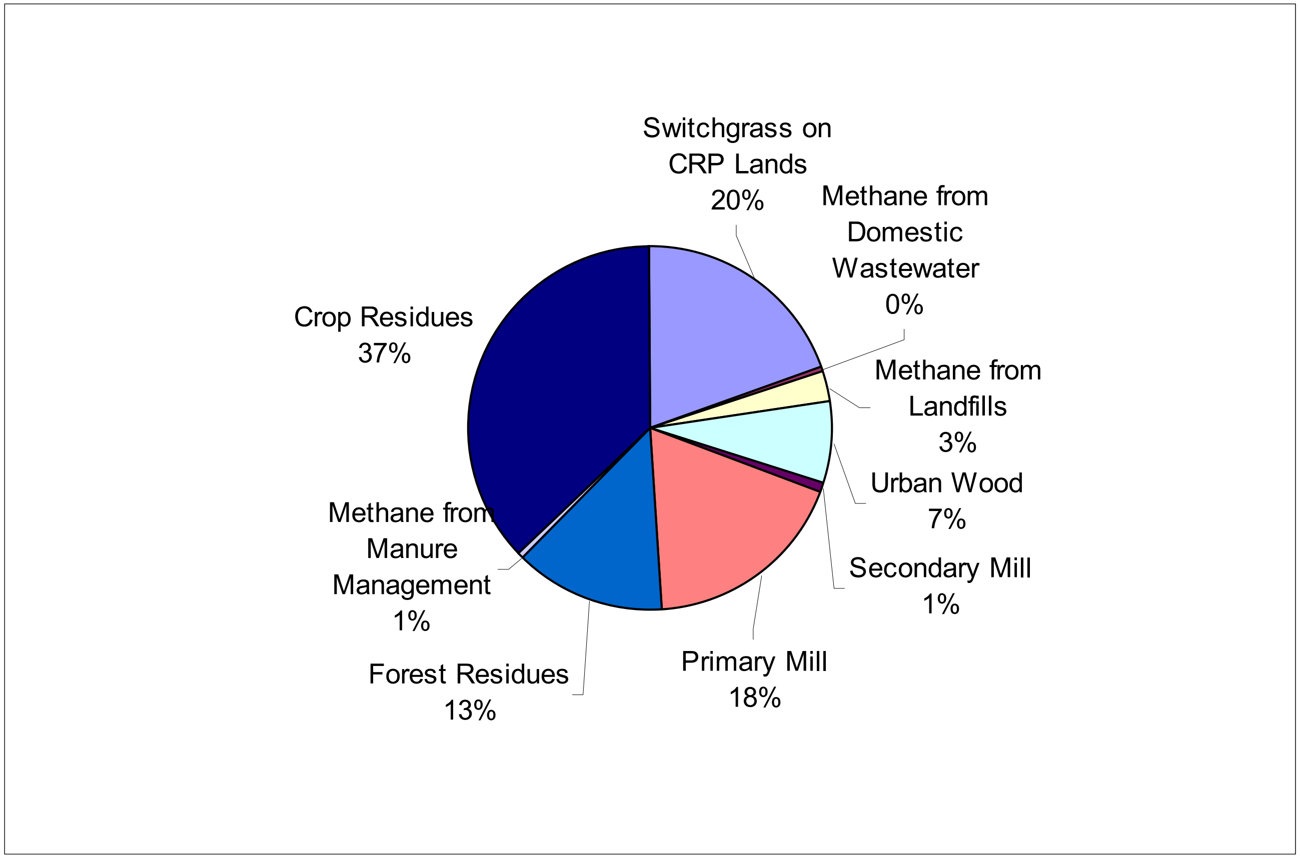

Figure 29 Percent Feedstock from Total Biomass

Table 10 Total Biomass Resources Available (Thousand tonnes/year) in the United States by State

State	Crop Residues	Switchgrass on CRP Lands	Forest Residues	Methane from Landfills	Methane from Manure Management	Primary Mill	Secondary Mill	Urban Wood	Methane from Domestic Wastewater	Total Biomass
Alabama	391	2,660	2,555	236	94	5,857	57	483	7	12,340
Alaska	0	0	738	11	0	231	2	65	1	1,049
Arizona	351	0	59	151	14	109	41	526	8	1,258
Arkansas	4,796	951	2,874	38	145	3,623	32	314	4	12,777
California	1,659	0	1,303	1,359	142	4,772	247	3,901	56	13,437
Colorado	1,550	0	70	273	28	181	41	451	7	2,601
Connecticut	0	1	78	66	0	75	24	376	6	625
Delaware	245	22	51	58	0.5	14	8	85	1	482
District of Columbia	0	0	0	0	0	0	0	56	1	57
Florida	3,263	460	1,778	457	19	1,901	130	1,678	26	9,711
Georgia	997	1,646	3,556	201	139	7,231	97	924	14	14,804
Hawaii	396	0	0	58	3	0	10	133	2	603
Idaho	1,788	0	873	7	31	4,400	20	129	2	7,250
Illinois	19,593	5,290	664	974	76	233	96	1,337	21	28,284
Indiana	8,976	1,609	863	526	77	574	71	715	10	13,421
Iowa	23,590	10,249	359	137	142	130	29	320	5	34,961
Kansas	7,614	6,274	134	139	22	29	19	332	4	14,568
Kentucky	1,722	1,822	2,055	250	34	1,433	52	454	7	7,830
Louisiana	4,335	1,072	3,384	166	6	3,577	33	474	7	13,054
Maine	0	0	2,890	27	0.2	421	15	133	2	3,489
Maryland	584	271	263	204	6	138	33	624	9	2,131
Massachusetts	0	0	89	206	0.1	113	52	687	10	1,157
Michigan	3,586	1,451	1,275	446	30	1,314	86	1,196	16	9,399
Minnesota	14,231	7,851	2,242	148	71	985	59	496	8	26,090
Mississippi	2,191	4,883	3,825	93	72	4,548	33	307	5	15,956
Missouri	6,007	8,473	1,840	273	120	1,036	69	613	9	18,439
Montana	1,560	0	704	21	4	1,937	13	106	1	4,347
Nebraska	10,931	3,344	72	48	102	57	13	189	3	14,759
Nevada	4	0	5	76	0.4	0	17	232	3	338

New Hampshire	0	0	986	40	0	925	18	126	2	2,097
New Jersey	91	11	29	497	0.3	17	58	894	14	1,612
New Mexico	168	0	71	31	60	165	9	191	3	697
New York	507	264	1,111	885	10	1,063	119	2,041	31	6,031
North Carolina	1,494	577	2,995	427	370	3,900	115	833	13	10,726
North Dakota	6,602	10,476	27	5	4	0.4	7	67	1	17,190
Ohio	5,001	1,587	796	647	41	786	124	1,272	19	10,272
Oklahoma	1,641	407	655	153	47	633	23	377	6	3,943
Oregon	567	0	1,041	125	17	6,454	86	382	6	8,676
Pennsylvania	810	672	1,679	642	23	1,358	127	1,238	20	6,569
Rhode Island	0	0	8	28	0	21	6	109	2	174
South Carolina	331	1,061	1,733	181	30	2,468	38	467	7	6,315
South Dakota	5,140	4,807	125	10	36	142	7	75	1	10,342
Tennessee	1,501	1,375	1,319	274	20	1,557	75	614	9	6,745
Texas	6,089	569	2,060	845	58	2,085	148	2,307	34	14,195
Utah	88	0	30	76	10	102	18	228	4	557
Vermont	0	4	496	21	3	103	9	65	1	701
Virginia	502	297	2,403	275	23	2,147	62	813	12	6,535
Washington	1,746	0	1,034	240	39	5,597	85	675	10	9,426
West Virginia	32	9	1,347	47	1	807	15	184	3	2,445
Wisconsin	4,419	3,126	2,011	273	19	1,621	69	548	9	12,096
Wyoming	106	0	58	8	2	255	4	59	1	492
U.S. Total	**157,194**	**83,572**	**56,612**	**12,380**	**2,189**	**77,125**	**2,615**	**30,902**	**465**	**423,054**

Appendix A: Analysis Methodology

Crop residues

Depending on the units in which the crop production is reported the following equations were used:

For crops reported in pounds (beans, peas, peanuts, cotton, canola, rice, potatoes, sunflower, and safflower):

BDT residue = crop production * crop to residue ratio * Dry Matter % / 2205

For crops reported in BU (barley, corn, oats, rye, sorghum, soybeans, wheat, and ***flaxseed***):

BDT residue = crop production * crop to residue ratio * Dry Matter % / K

For crops reported in short (US) tons (sugar cane):

BDT residue = crop production * crop to residue ratio * Dry Matter % * 0.9072

Where:

BDT – Bone dry tonnes

BU - Bushel

1 metric ton (MT) = 2205 pounds

K - BU to MT conversion or 2205 / Bushel weight (in Lbs) see Table 1

0.9072 – conversion from short (US) tons to metric tons

Table A-1: Crop to Residue Ratio and Moisture Content of Selected Crops

Crop	Ratio of Residue to Crop Volume*	Moisture Content (Percent)**	Bushel Weight (lb)***
Barley	1.2	14.5	48
Canola	2.2	8.0	50
Corn	1.0	15.5	56
Cotton	4.5	12.0	32
Dry Beans	1.2	13.0	60
Flaxseed	1.2	8.0	56
Oats	1.3	14.0	32
Peanuts	1.0	9.9	22
Peas	1.5	9.8	60
Potatoes	0.4	13.3	60
Rice	1.4	15.0	45

Rye	1.6	10.0	56
Safflower	1.2	8.0	40
Sorghum	1.4	12.0	56
Soybeans	2.1	13.0	60
Sugar Cane	1.6	62.8	50
Sunflower	2.1	10.0	30
Wheat	1.3	13.5	60

Sources:

* Hall and R. Overend, eds., 1987; Kristoferson ea '91; Ryan ea '91; Food and Agriculture of the United States (FAO); Agriculture and Agri–Food Canada.

** "Grain Moisture Content Effects and Management", Dr.Kenneth J. Hellevang, North Dakota State University; The college of Agriculture, Food and Environmental Science – University of Minnesota; Department of Agronomy, University of Missouri – Columbia; USDA - National Resources Conservation Service, Plant Nutrient database.
*** National Association of State Departments of Agriculture (NASDA); University of Missouri's Agricultural Publication G4020, by William J. Murphy

Methane Emissions from Manure Management

The following steps were used to calculate methane emissions from manure management systems, based on EPA State Workbook: Methodologies for Estimating Greenhouse Gas Emissions, Second Edition, 1995, Workbook 7 Methane Emissions from Manure Management.

Determining the amount of volatile solids (VS) produced by each animal type

The following equation was used to calculate pounds of volatile solids produced by each animal type:

Equation 1:

VSi produced per animal type = Animal population (head) * TAMi * vsi

Where:

VSi.....=..Total VS produced (lbs./yr.) for animal type i
TAMi.....=..Typical animal mass for animal type i (lbs./head) (Table 2)
VSi.....=..Average annual volatile solids production per unit of animal mass of animal type i (VS per pound of animal mass) (Table 2)

Table A-2. U.S. Average Animal Size and vs Production			
Animal Type		Typical Animal Mass (TAM) lbs	Volatile Solids (vs) lbs VS/ lb animal mass/yr
Feedlot Beef Cattle	Steers/Heifers	915	2.6
Other Beef Cattle	Calves	397	2.6
	Heifers	794	2.6
	Steers	794	2.6
	Cows	1102	2.6
	Bulls	1587	2.6
Dairy Cattle	Heifers	903	3.65
	Cows	1345	3.65
Swine	Market	101	3.1
	Breeding	399	3.1
Poultry	Layers	3.5	4.4
	Broilers	1.5	6.2
	Turkeys	7.5	3.32
Other	Sheep	154	3.36

Note: Due to lack of separate data of market and breeding swine we adopted the numbers for market swine.

Estimate the methane emissions for each manure management system and animal type

The solution of Equation 1, total amount of volatile solids, and additional data were then used in Equation 2 to calculate total methane emissions:

Equation 2:

CH4 emissions for animal i on system j (cu.ft./yr.)= VSi * Bi * MCFj * WS%ij

Where:

VSi .....=..Total VS produced (lbs./yr.) for animal type I (Equation 1)
Bi.......=..Maximum methane producing capacity per pound of VS for animal type i (ft3/lbs. VS) (Table 3)
MCFj.....=..Methane conversion factor for each manure system j (Table 4)
WS%ij....=..Percent of animal type i's manure managed in manure system j (%) (U.S.EPA, 1995b, (7-1 - 7-7).

Table A-3 Maximum Methane Producing Capacity Adopted For U.S. Estimates			
Animal Type, Category		Maximum Potential Emissions (B_i)	Reference
Cattle:	Beef in Feedlots	5.29	Hashimoto et al. (1981)
	Beef Not in Feedlots	2.72	Hashimoto et al. (1981)
	Dairy	3.84	Morris (1976)
Swine:	Breeder	5.77	Summers & Bousfield (1980)
	Market	7.53	Chen (1983)
Poultry:	Layers	5.45	Hill (1982 & 1984)
	Broilers	4.81	Safley et al. (1992)
	Turkeys	4.81	Safley et al. (1992)
	Ducks	5.13	Safley et al. (1992)
Sheep:	In Feedlots	5.77	Safley et al. (1992)
	Not in Feedlots	3.04	Safley et al. (1992)
Goats:		2.72	Safley et al. (1992)
Horses and Mules:		5.29	Ghosh (1984)

Table A-4. Methane Conversion Factors for U.S. Livestock Manure Systems*

State	Pasture, Range & Paddocks	Drylot	Solid Storage	Daily Spread	Liquid/ Slurry
Alabama	1.4%	1.9%	1.4%	0.4%	29.0%
Arizona	1.4%	1.9%	1.4%	0.4%	28.9%
Arkansas	1.3%	1.8%	1.3%	0.4%	27.6%
California	1.2%	1.4%	1.2%	0.3%	21.9%
Colorado	0.9%	1.0%	0.9%	0.2%	18.2%
Connecticut	0.9%	1.0%	0.9%	0.2%	18.5%
Delaware	1.2%	1.4%	1.2%	0.3%	22.6%
Florida	1.5%	2.4%	1.5%	0.6%	38.6%
Georgia	1.4%	1.8%	1.4%	0.4%	29.0%
Idaho	0.8%	0.8%	0.8%	0.2%	15.5%
Illinois	1.1%	1.3%	1.1%	0.3%	22.8%
Indiana	1.0%	1.2%	1.0%	0.3%	21.5%
Iowa	0.9%	1.1%	0.9%	0.2%	20.7%
Kansas	1.1%	1.5%	1.1%	0.3%	24.7%
Kentucky	1.2%	1.5%	1.2%	0.3%	23.8%
Louisiana	1.4%	2.1%	1.4%	0.5%	32.5%
Maine	0.8%	0.8%	0.8%	0.2%	15.5%
Maryland	1.1%	1.2%	1.1%	0.3%	21.0%
Massachusetts	0.9%	1.0%	0.9%	0.2%	18.1%
Michigan	0.8%	0.9%	0.8%	0.2%	17.0%
Minnesota	0.8%	0.8%	0.8%	0.2%	18.0%
Mississippi	1.4%	1.9%	1.4%	0.4%	29.3%
Missouri	1.1%	1.4%	1.1%	0.3%	24.1%
Montana	0.7%	0.8%	0.7%	0.2%	15.8%

Nebraska	1.0%	1.1%	1.0%	0.2%	20.8%
Nevada	1.2%	1.4%	1.2%	0.3%	22.1%
New Hampshire	0.8%	0.8%	0.8%	0.2%	16.3%
New Jersey	1.0%	1.1%	1.0%	0.3%	20.6%
New Mexico	1.2%	1.3%	1.2%	0.3%	21.3%
New York	0.9%	0.9%	0.9%	0.2%	18.1%
North Carolina	1.3%	1.5%	1.3%	0.3%	24.5%
North Dakota	0.7%	0.7%	0.7%	0.2%	16.8%
Ohio	1.0%	1.1%	1.0%	0.2%	20.2%
Oklahoma	1.4%	1.9%	1.4%	0.4%	28.7%
Oregon	1.1%	1.1%	1.1%	0.2%	16.2%
Pennsylvania	0.9%	1.0%	0.9%	0.2%	18.7%
Rhode Island	1.0%	1.1%	1.0%	0.2%	18.7%
South Carolina	1.3%	1.7%	1.3%	0.4%	27.3%
South Dakota	0.8%	0.9%	0.8%	0.2%	19.1%
Tennessee	1.3%	1.6%	1.3%	0.3%	24.8%
Texas	1.4%	2.1%	1.4%	0.5%	31.7%
Utah	0.9%	1.0%	0.9%	0.2%	17.4%
Vermont	0.8%	0.8%	0.8%	0.2%	16.6%
Virginia	1.2%	1.4%	1.2%	0.3%	22.5%
Washington	1.0%	1.0%	1.0%	0.2%	15.5%
West Virginia	1.2%	1.3%	1.2%	0.3%	21.4%
Wisconsin	0.8%	0.8%	0.8%	0.2%	17.0%
Wyoming	0.8%	0.8%	0.8%	0.2%	15.9%

Other Systems: Pit Storage for less than 30 days is assumed to have an MCF equal to 50% of the MCF for Liquid/Slurry. Pit Storage for more than 30 days is assumed to have an MCF equal to liquid/slurry. Anaerobic lagoons are assumed to have an MCF of 90%; litter and deep pit stacks an MCF of 10%.

Conversion of all units to tons of methane and summation of emissions over all manure management types

CH_4 cu.ft./yr. * 0.0413 / 2205

0.0413 - Density of methane (lbs./cu.ft.) conversion factor to pounds
2205 – Pounds to metric tons

Forest Residues

Data on volume (cubic feet) of logging residues and other removals by county was collected from the Timber Products Output Mapmaker version 1.0. Then the following volume conversion factor was used for computations[8]:

1 mcf= 0.0125 MBDT where 1 mcf= 1000 ft 3 and 1 MBDT = 1000 bone dry tons

[8] Schmidt, D., Pinapati, V., Opportunities for small biomass power systems, University of North Dakota, November 2000

Primary Mill Residues

Data on volume (cubic feet) of primary mill residues by county was collected from the Timber Products Output Mapmaker version 1.0. Then the following volume conversion factor was used for computations[9]:

1 mcf= 0.0125 MBDT where 1 mcf= 1000 ft 3 and 1 MBDT = 1000 bone dry tons

Secondary Mill Residues

The number of businesses by county was gathered from the U.S. Census Bureau, 2002 County Business Patterns, and the following methodology was applied:

For pallet and lumber companies:

N * 300 * 0.9072

Where

N - Number of companies in a county

300 – According to Wiltsee[9] about 300 tons/year is the wood residue generated by a company

0,9072 - US to metric tons conversion

For woodworking companies:

N * tons/year * 0.9072

Where

N - Number of companies in a county

Tons/year - According to Wiltsee's study,[9] a small company typically generates between 5 and 20 tons/year of wood waste. Based on number of employees a conservative assumption of the wood waste generated by a company was applied:

- 1 to 19 employees – 5 tons/year
- 20 – 99 employees – 10 tons/year
- 100 – 499 employees – 15 tons/year
- 500 – 1000 + employee – 20 tons/year
- 0.9072 - US to metric tons conversion

10 % moisture was assumed for the wood residues generated by the secondary wood products mills.

[9] Wiltsee, G, Urban Wood Waste Resource Assessment, Appel Consultant, Inc. Valencia, CA. November, 1998.

Urban Wood Waste

MSW wood and yard waste: MSW per capita by state was collected from the BioCycle Journal[10]. Then county population data (U.S. Census Bureau, 2000) with assumptions from Wiltsee's study[10] were used to estimate the total MSW generation by county. According to this study, wood is between 3% and 5% from total MSW, depending on whether wood and yard waste separation and recycling is practiced.

Utility tree trimming and/or private tree companies: Data on forestry support activities and electric power distribution business establishments by county were gathered from the U.S. Census Bureau, 2002 County Business Patterns. The assumption that a single tree service crew typically generates about 1,000 tons/year of wood waste[11] was used to calculate the wood waste generated by utility tree trimming and private tree companies.

Construction/Demolition (C/D) wood: The construction and demolition wood was estimated using the following equation adopted from Wiltsee's analysis[12]:

C/D wood, tons/year = 0.09 * Population

Methane Emissions from Landfills

Estimated methane generation in tons/year is based on methodology adopted from EPA State Workbook: Methodologies for Estimating Greenhouse Gas Emissions, Second Edition, 1995, Workbook 5 Methane Emissions from Landfills.

Table A-5 Arid States (states with average annual rainfall less than 25 inches)

Arizona	Montana	North Dakota
California	Nebraska	South Dakota
Colorado	Nevada	Utah
Idaho	New Mexico	Wyoming

Source: Department of Commerce (1988)

Small Landfills (WIP<1.1 million tons):

Arid: CH4 (tons/year) = WIP (tons) * 0.27 * 0.0070 *Equation 1*

Non-arid: H4 (tons/year) = WIP (tons) * 0.35 * 0.0070 *Equation 2*

Large Landfills (WIP>= 1.1 million tons):

Arid: CH4 (tons/year) = (WIP (tons) *0.16) + 419023 * 0.0070 *Equation 3*

Non-arid: CH4 (tons/year) = (WIP (tons) * 0.26) + 419023 * 0.0070 *Equation 4*

Where:

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[10] Kaufman, S., Goldstein, N., Millrath, K., Themelis, N., The State of Garbage in America, BioCycle Journal of Composting & Recycling, January 2004

[11] Wiltsee, G, Urban Wood Waste Resource Assessment, Appel Consultant, Inc. Valencia, CA. November, 1998.

WIP – Waste in place

0.27, 0.35, 0.16, and 0.26 - conversion factor for tons of waste to cu.ft./day methane

419023 - Constant recommended in the State Workbook (5-6)

0.0070 - Conversion factor from cu.ft./day to tons/yr or:

$$\frac{365\,(days\ /\ year)\ x\ 19.2\,(g\ /\ ft^3)}{453.49\,(g\ /\ lb)\ x\ 2205\,(lb\ /\ \textit{metric}\ ton)} = 0.0070\,\frac{(tonCH4\ /\ year)}{(ft^3\ /\ day)}$$

Methane Emissions from Domestic Wastewater Treatment

Methodology adopted from the EPA Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2001, Wastewater Treatment.

Methane (CH_4) Generation = (POP) * (BOD) * (PAD) * (CH_4P)

Where

POP = county population (2000 Census data)

BOD = production of BOD per capita per year (0.065 kg of wastewater BOD is produced per day per capita)

PAD = percentage of BOD anaerobically digested per year (16.25%)

CH_4P = methane generation potential per kg of BOD (emission factor of 0.6 kg CH4/kg of BOD)

Dedicated Energy Crops on Conservation Reserve Program Lands

The amount of energy crops that could be potentially grown on CRP lands was calculated using the median estimated yield (dry tonnes/acre/yr) of unirrigated energy crops (switchgrass and short rotation woody crops – willow and hybrid poplar) data developed by the Oak Ridge National Laboratory.

Dedicated Energy Crops on Abandoned Mine Lands

Data on the location of abandoned mine lands was obtained from the U.S. Department of the Interior, Office of Surface Mining. The median estimated yield (dry tonnes/acre/yr) of unirrigated energy crops (switchgrass and short rotation woody crops – willow and hybrid poplar) by county is based on the data developed by the Oak Ridge National Laboratory.

Glossary of Terms

Anaerobic Digestion: Anaerobic digestion involves the breakdown of organic waste by bacteria in an oxygen-free environment. It is commonly used as a waste treatment process but also produces a methane-rich biogas which can be used to generate heat and/or electricity**.**

Biomass: An energy resource derived from organic matter, including the by-products from the timber industry, agricultural crops, raw material from the forest, major parts of household waste and wood.

Biomass potential:

- **Theoretical** is an estimate of the standing biomass based on calculation or measurement of the net primary productivity of the biome. This in turn is related to all of the factors shown in Figure 1 (land use, climatic and soil characteristics, topography, etc.)[12].
- **Technical** is based on the accessible biomass with respect to constraints of land use, and the majority of the quantity depends on assumptions and factors that relate population to the amount of residue generation. These factors are often local and subject to the level of technology (harvest, collection etc) available, and vary between different studies.
- **Economic** is a subset of the technical potential with the addition of screens based on harvest costs, logistics, and the available material to service conversion plants of sufficient scale to be economic. The final outcome of this type of assessment is a supply curve either at the field or forest edge[13] or the delivered product such as electricity[14].

Biome: A distinct ecological community of plants and animals living together in a particular climate. There are seven kinds of biomes in the world: tundra, taiga, temperate forest, tropical rainforest, desert, grassland, and ocean.

Combined heat and power (CHP) technologies: A group of technologies that produce electricity and heat (also known as cogeneration) in a single, integrated system. It converts as much as 90% of the fuel into usable energy.

Dedicated energy crops: Include short rotation woody crops, such as hybrid poplar, hybrid willow, and herbaceous crops such as switchgrass, grown specifically for use as an energy source.

Direct combustion technology: Involves the oxidation of biomass with excess air in a process that yields hot flue gases that are used to produce steam in boilers.

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[12] Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply, Oak Ridge National Laboratory and U.S. Department of Agriculture, April 2005

[13] Biomass Feedstock Availability in the United States: 1999 State Level Analysis, Marie E. Walsh, Robert L. Perlack, Anthony Turhollow, Daniel de la Torre Ugarte, Denny A. Becker, Robin L. Graham, Stephen E. Slinsky, and Daryll E. Ray, Oak Ridge National Laboratory, Oak Ridge, TN

[14] Western Governor's Association, Clean and Diversified Energy Advisory Committee (CDEAC), Biomass Task Force, http://www.westgov.org/wga/initiatives/cdeac/Biomassdraft9-6.pdf (December 2, 2005)

Ethanol: An alcohol fuel made from the sugars found in grains, such as corn, sorghum, and wheat, as well as potato skins, rice, sugar cane, sugar beets, and yard clippings.

Feedstock: A raw material that can be converted to one or more useful products.

Gasification: Biomass gasification is conversion of solid biomass (wood, agriculture residues etc.) in to a combustible gas mixture normally called "producer gas" (or low Btu gas).

Methane: A colorless, flammable, odorless hydrocarbon gas (CH_4) and the major component of natural gas. It is also a greenhouse gas, and an important source of hydrogen.

Volatile solid: A solid or liquid material that easily vaporizes.

References

1. Antares Group. Inc, Biomass residue supply curves for the United States, 1999.
2. Biomass Energy: A research commitment on Global Warming, Renewable Energy, and Reforestation by using Nature's own “power plants”... Trees!, Planet Power: Energy and the Environment (http://www.treepower.org/).
3. Fehrs, J., Secondary mill residues and urban wood waste quantities in the United States, December 1999.
4. *FEMP Focus* - Winter/Spring 2005 Wastewater Digester Gas Can Produce High Quality Methane Fuel for Federal Facilities.
5. Glenn, J., The State of Garbage, BioCycle Journal of Composting & Recycling, April 1998, pp. 32-43.
6. Graham, R., Allison, L., and Becker, D., The Oak Ridge Energy Crop County Level Database, December 20th, 1996 version.
7. Kaufman, S., Goldstein, N., Millrath, K., Themelis, N., The State of Garbage in America, BioCycle Journal of Composting & Recycling, January 2004.
8. McKeever. David B., Wood residue quantities in the U.S., BioCycle Journal of Composting & Recycling, January 1998.
9. NEOS Corp., Lignocellulosic feedstock resource assessment. Golden, CO, 1998.
10. NEOS Corp., Urban tree residues: results of the first national inventory. Lakewood, CO, 1994.
11. Schmidt, D., Pinapati, V., Opportunities for small biomass power systems, University of North Dakota, November 2000.
12. Wiltsee, G, Urban Wood Waste Resource Assessment, Appel Consultant, Inc. Valencia, CA. November, 1998.
13. U.S. Department of Agriculture, Farm Service Agency, County CRP Signup 26 Information.
14. U.S. Department of Agriculture, Forest Service, Forest Inventory and Analysis, Timber Product Output Database Retrieval System.
15. U.S. Department of Agriculture, Forest Service, Forest resources of the United States, 1997.
16. U.S. Department of Agriculture, National Agricultural Statistical Service, 2002 Washington, DC.
17. U.S. Department of the Interior, Office of Surface Mining, Abandoned Mine Land Inventory System (AMLIS), Washington, DC.
18. U.S. Environmental Protection Agency, Characterization of Municipal Solid Waste in the United States, 1998.
19. U.S. Environmental Protection Agency, Landfill Methane Outreach Program (LMOP)database.

20. U.S. Environmental Protection Agency, State Workbook: Methodologies for Estimating Greenhouse Gas Emissions, Second Edition, 1995, Workbook 7 Methane Emissions from Manure Management.
21. U.S. Environmental Protection Agency, State Workbook: Methodologies for Estimating Greenhouse Gas Emissions, Second Edition, 1995, Workbook 5 Methane Emissions from Landfills.
22. U.S. Environmental Protection Agency, Inventory of U.S. greenhouse gas emissions and sinks: 1990 -2003, Waste, EPA, April 2005.

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