INTRODUCTION TO BIOMASS

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Biomass Energy Overview

In 2010, biomass energy production contributed 4.3 quadrillion Btu (British thermal units) of energy to the 75 quadrillion Btu of energy produced in the United States or about 5.7% of total energy production. Since a substantial portion of U.S. energy is imported, the more commonly quoted figure is that biomass consumption amounted to 4.3 quadrillion Btu of energy of the 98 quadrillion Btu of energy consumed in the United States in 2010 or about 4.4%. At present, wood resources contribute most to the biomass resources consumed in the United States and most of that is used in the generation of electricity and industrial process heat and steam. However, the contribution of biofuels has nearly tripled since 2005 and now accounts for about 43% of all biomass consumed. While most biofuels feedstocks are currently starches, oils and fats derived from the agricultural sector, whole plants and plant residues will soon be an important feedstock for cellulosic biofuels. Algae are being developed as a source of both oil and cellulosic feedstocks. The industrial sector (primarily the wood products industry) used about 2.2 quadrillion Btu in 2010. The residential and commercial sectors consume 0.05 quadrillion Btu of biomass; however, this figure may understate consumption in these sectors due to unreported consumption, such as home heating by wood collected on private property. The use of biomass fuels such as ethanol and biodiesel by the transportation sector is now at about 1 quadrillion Btu. This is less than the total amount of biofuels produced because some liquid biofuels are used by other sources.

The tables in the introduction showing the accounting of energy production and consumption are all derived from Energy Information Administration (EIA) reports. Information on assumed Btu content of most fuels and the assumptions used in estimating the total Btus consumed in the US can be found in the EIA Monthly Energy Review at: http://www.eia.gov/totalenergy/data/monthly/pdf/sec13.pdf. A key point is that gross heat contents (higher heating values) of fuels and biomass feedstocks are used rather than the net heat contents (lower heating values) commonly used in Europe. Differences may range from 2 to 10%. The assumptions for the gross heat content of wood and consumption estimation were found under a discussion of "wood conversion to Btu" in the EIA glossary that can be accessed at http://www.eia.gov/tools/glossary/. The EIA glossary explains that many factors can affect wood heat content but EIA calculations always assume 20 million Btu per cord of wood. This is actually slightly higher than the heat content values for wood found from multiple other sources. A table, showing both higher and lower heating values for many biomass fuels, is included in appendix A of the Biomass Energy Data Book. Factors for translating cords to other units of wood are also found in the appendix A. The EIA glossary also notes that EIA biomass waste data includes energy crops grown specifically for energy production. This is likely due to the fact that insufficient amounts of dedicated energy crops are currently being used to warrant separate tracking.

The Renewable Fuels Association characterized 2007 as a year that ushered in a new energy era for America. The enactment of the Energy Independence and Security Act of 2007 (H.R. 6) coupled increased vehicle efficiency with greater renewable fuel use. The law increased the Renewable Fuel Standard (RFS) to 36 billion gallons of annual renewable fuel use by 2022 and required that 60 percent of the new RFS be met by advanced biofuels, including cellulosic ethanol. The recent increase in the percentage of biomass consumed in the U.S. is largely due to the increased production and consumption of biofuels.

Biomass energy production involves the use of a wide range of technologies to produce heat, steam, electricity and transportation fuels from renewable biomass feedstocks. Descriptions of many of the biomass technologies currently in commercial use or being tested are included in the Biomass Energy Data Book. Information on the characteristics and availability of utilized or potential biomass feedstocks as well as information on relevant policies are also included. Information on economics and sustainability is included to a limited extent since the limited information publically available is generally based on estimates rather than factual data.

Legislation passed in December 2007 created a large incentive to increase the total amount of renewable biofuels available in the U.S. with nearly half to be derived from lignocellulosic biomass, but excluded the use of biomass from some sources.

Section: INTRODUCTION
Energy Independence and Security Act (EISA) 2007

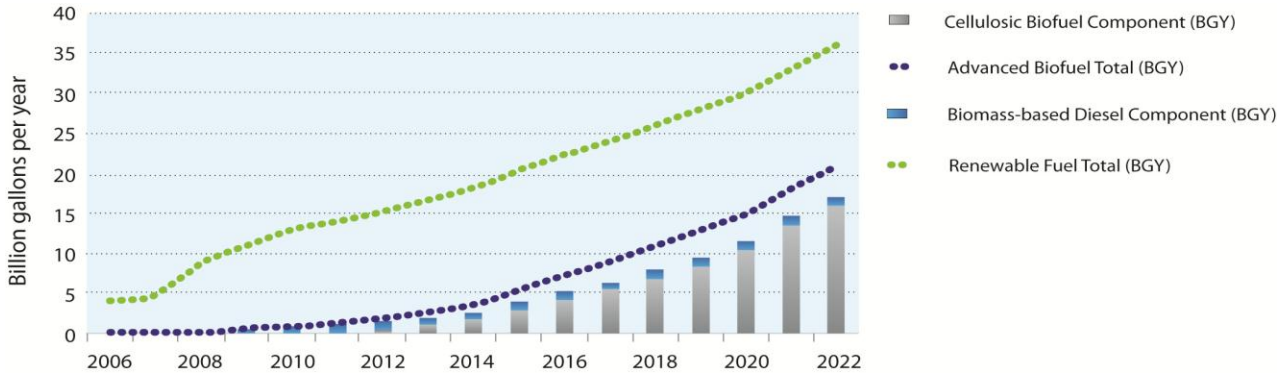
EISA legislation was signed into law on December 19, 2007. The law contains a number of provisions to increase energy efficiency and the availability and use of renewable energy. One key provision of EISA is the setting of a revised Renewable Fuels Standard (RFS). The revised RFS mandates the use of 36 billion gallons per year (BGY) of renewable fuels by 2022. The revised RFS has specific fuel allocations for 2022 that include use of:

- 16 BGY of cellulosic biofuels
- 14 BGY of advanced biofuels
- 1 BGY of biomass-based biodiesel
- 15 BGY of conventional biofuels (e.g., corn starch-based ethanol).

(See, 42 U.S.C. 7545(o)(2)) EISA legislation also established new definitions and criteria for both renewable fuels (e.g., greenhouse gas reduction thresholds) and the renewable biomass used to produce the fuels. Renewable biomass includes, generally:

- Crops from previously cleared non-forested land
- Trees from actively managed plantations on non-federal land
- Residues from non-federal forestland that is deemed not to be critically imperiled or rare
- Biomass from the immediate vicinity of buildings or public infrastructure at risk from wildfires
- Algae
- Separated yard or food waste.

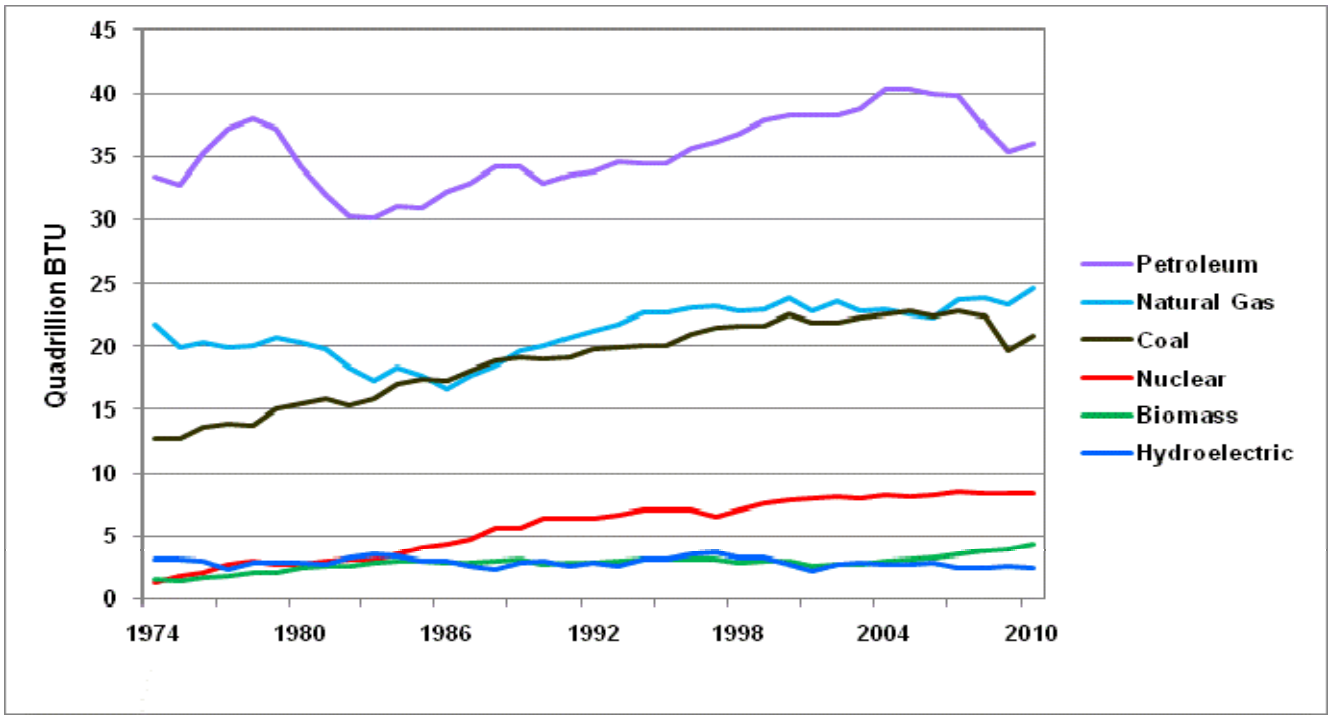
(See, 42 U.S.C. 7545(o)(1)(I)) Excluded from the qualifying renewable biomass are resources from ecologically sensitive or protected lands, biomass from federal forestlands, biomass from newly cleared or cultivated land, and merchantable biomass from naturally regenerated forestlands.



Above write-up extracted from: Perlack, R. D., and B. J. Stokes (leads), *U.S. Billion-Ton Update: Biomass Supply for a Bioenergy and BiproductsIndustry* , ORNL/TM-2010/224, Oak Ridge National Laboratory, Oak Ridge, TN, 2011, p. 227.

A variety of biomass feedstocks are currently used to generate electricity, produce heat, and liquid transportation fuels. According to EIA, biomass contributes nearly 4.3 quadrillion Btu (British thermal unit) and accounts for more than 4% of total U.S. primary energy consumption. In 2009, the share of biomass in total U.S. energy consumption exceeded 4% for the first time. Over the last 30 years, the share of biomass in total primary energy consumption has averaged less that 3.5%. However, as shown in the figure below there has been a gradual increase in biomass consumption that started in the early 2000s. This increase is due to ethanol production. The EIA estimates include the energy content of the biofuels (ethanol and biodiesel) feedstock minus the energy content of liquid fuel produced.

Section: INTRODUCTION
Primary Energy Consumption by Major Fuel Source, 1974 - 2010



Source:
U.S. Department of Energy, Energy Information Administration, *Monthly Energy Review*, July 2011, Washington, D.C., Table 1.3.
http://www.eia.gov/totalenergy/data/monthly/

In 2010 biomass accounted for just over half of the renewable energy production in the United States.

Section: INTRODUCTION
Energy Production by Source, 1973-2010
(Quadrillion Btu)

	Fossil Fuels						Renewable Energy[a]						
Year	Coal	Natural Gas (Dry)	Crude Oil[b]	Natural Gas Plant Liquids	Total	Nuclear Electric Power	Hydro-electric Power[c]	Biomass	Geo-thermal	Solar	Wind	Total	Total
1973	13.992	22.187	19.493	2.569	58.241	0.910	2.861	1.529	0.020	NA	NA	4.433	63.585
1974	14.074	21.210	18.575	2.471	56.331	1.272	3.177	1.540	0.026	NA	NA	4.769	62.372
1975	14.989	19.640	17.729	2.374	54.733	1.900	3.155	1.499	0.034	NA	NA	4.723	61.357
1976	15.654	19.480	17.262	2.327	54.723	2.111	2.976	1.713	0.038	NA	NA	4.768	61.602
1977	15.755	19.565	17.454	2.327	55.101	2.702	2.333	1.838	0.037	NA	NA	4.249	62.052
1978	14.910	19.485	18.434	2.245	55.074	3.024	2.937	2.038	0.031	NA	NA	5.039	63.137
1979	17.540	20.076	18.104	2.286	58.006	2.776	2.931	2.152	0.040	NA	NA	5.166	65.948
1980	18.598	19.908	18.249	2.254	59.008	2.739	2.900	2.476	0.053	NA	NA	5.485	67.232
1981	18.377	19.699	18.146	2.307	58.529	3.008	2.758	2.596	0.059	NA	NA	5.477	67.014
1982	18.639	18.319	18.309	2.191	57.458	3.131	3.266	2.664	0.051	NA	NA	6.034	66.623
1983	17.247	16.593	18.392	2.184	54.416	3.203	3.527	2.904	0.064	NA	0.000	6.561	64.180
1984	19.719	18.008	18.848	2.274	58.849	3.553	3.386	2.971	0.081	0.000	0.000	6.522	68.924
1985	19.325	16.980	18.992	2.241	57.539	4.076	2.970	3.016	0.097	0.000	0.000	6.185	67.799
1986	19.509	16.541	18.376	2.149	56.575	4.380	3.071	2.932	0.108	0.000	0.000	6.223	67.178
1987	20.141	17.136	17.675	2.215	57.167	4.754	2.635	2.875	0.112	0.000	0.000	5.739	67.659
1988	20.738	17.599	17.279	2.260	57.875	5.587	2.334	3.016	0.106	0.000	0.000	5.568	69.030
1989	21.360	17.847	16.117	2.158	57.483	5.602	2.837	3.160	0.162	0.055	0.022	6.391	69.476
1990	22.488	18.326	15.571	2.175	58.560	6.104	3.046	2.735	0.171	0.060	0.029	6.206	70.870
1991	21.636	18.229	15.701	2.306	57.872	6.422	3.016	2.782	0.178	0.063	0.031	6.238	70.532
1992	21.694	18.375	15.223	2.363	57.655	6.479	2.617	2.933	0.179	0.064	0.030	5.993	70.127
1993	20.336	18.584	14.494	2.408	55.822	6.410	2.892	2.910	0.186	0.066	0.031	6.263	68.495
1994	22.202	19.348	14.103	2.391	58.044	6.694	2.683	3.030	0.173	0.069	0.036	6.155	70.893
1995	22.130	19.082	13.887	2.442	57.540	7.075	3.205	3.102	0.152	0.070	0.033	6.703	71.319
1996	22.790	19.344	13.723	2.530	58.387	7.087	3.590	3.157	0.163	0.071	0.033	7.167	72.641
1997	23.310	19.394	13.658	2.495	58.857	6.597	3.640	3.111	0.167	0.070	0.034	7.180	72.634
1998	24.045	19.613	13.235	2.420	59.314	7.068	3.297	2.933	0.168	0.070	0.031	6.659	73.041
1999	23.295	19.341	12.451	2.528	57.614	7.610	3.268	2.969	0.171	0.069	0.046	6.683	71.907
2000	22.735	19.662	12.358	2.611	57.366	7.862	2.811	3.010	0.164	0.066	0.057	6.262	71.490
2001	23.547	20.166	12.282	2.547	58.541	8.033	2.242	2.629	0.164	0.065	0.070	5.318	71.892
2002	22.732	19.439	12.163	2.559	56.894	8.143	2.689	2.712	0.171	0.064	0.105	5.899	70.936
2003	22.094	19.691	12.026	2.346	56.157	7.959	2.825	2.815	0.175	0.064	0.115	6.149	70.264
2004	22.852	19.093	11.503	2.466	55.914	8.222	2.690	3.011	0.178	0.065	0.142	6.248	70.384
2005	23.185	18.574	10.963	2.334	55.056	8.160	2.703	3.141	0.181	0.066	0.178	6.431	69.647
2006	23.790	19.022	10.801	2.356	55.968	8.215	2.869	3.226	0.181	0.068	0.264	6.608	70.792
2007	23.493	19.825	10.721	2.409	56.447	8.455	2.446	3.489	0.186	0.076	0.341	6.537	71.440
2008	23.851	20.703	10.509	2.419	57.482	8.427	2.511	3.867	0.192	0.089	0.546	7.205	73.114
2009	21.627	21.095	11.348	2.574	56.644	8.356	2.669	3.915	0.200	0.098	0.721	7.603	72.603
2010	22.077	22.095	11.669	2.686	58.527	8.441	2.509	4.310	0.212	0.109	0.924	8.064	75.031

Source:
U.S. Department of Energy, Energy Information Administration, *Monthly Energy Review,* June 2011. Table 1.2, www.eia.doe.gov/emeu/mer/overview.html

Note: NA = Not available.

[a]Most data are estimates.
[b]Includes lease condensate.
[c]Conventional hydroelectric power.

Section: INTRODUCTION
Energy Consumption by Source, 1973-2010
(Quadrillion Btu)

	Fossil Fuels					Renewable Energy[a]						
Year	Coal	Natural Gas[b]	Petro-leum[c,d]	Total[e]	Nuclear Electric Power	Hydro-electric Power[f]	Biomass[d,g]	Geo-thermal	Solar	Wind	Total	Total[d,h]
1973	12.971	22.512	34.837	70.314	0.910	2.861	1.529	0.020	NA	NA	4.411	75.684
1974	12.663	21.732	33.454	67.905	1.272	3.177	1.540	0.026	NA	NA	4.742	73.962
1975	12.663	19.948	32.732	65.357	1.900	3.155	1.499	0.034	NA	NA	4.687	71.965
1976	13.584	20.345	35.178	69.107	2.111	2.976	1.713	0.038	NA	NA	4.727	75.975
1977	13.922	19.931	37.124	70.991	2.702	2.333	1.838	0.037	NA	NA	4.209	77.961
1978	13.766	20.000	37.963	71.854	3.024	2.937	2.038	0.031	NA	NA	5.005	79.950
1979	15.040	20.666	37.122	72.891	2.776	2.931	2.152	0.040	NA	NA	5.123	80.859
1980	15.423	20.235	34.205	69.828	2.739	2.900	2.476	0.053	NA	NA	5.428	78.067
1981	15.908	19.747	31.932	67.571	3.008	2.758	2.596	0.059	NA	NA	5.414	76.106
1982	15.322	18.356	30.232	63.888	3.131	3.266	2.663	0.051	NA	NA	5.980	73.099
1983	15.894	17.221	30.052	63.152	3.203	3.527	2.904	0.064	NA	0.000	6.496	72.971
1984	17.071	18.394	31.053	66.506	3.553	3.386	2.971	0.081	0.000	0.000	6.438	76.632
1985	17.478	17.703	30.925	66.093	4.076	2.970	3.016	0.097	0.000	0.000	6.084	76.392
1986	17.260	16.591	32.198	66.033	4.380	3.071	2.932	0.108	0.000	0.000	6.111	76.647
1987	18.008	17.640	32.864	68.521	4.754	2.635	2.875	0.112	0.000	0.000	5.622	79.054
1988	18.846	18.448	34.223	71.557	5.587	2.334	3.016	0.106	0.000	0.000	5.457	82.709
1989	19.070	19.602	34.209	72.911	5.602	2.837	3.159	0.162	0.055	0.022	6.235	84.786
1990	19.173	19.603	33.552	72.332	6.104	3.046	2.735	0.171	0.059	0.029	6.041	84.485
1991	18.992	20.033	32.846	71.880	6.422	3.016	2.782	0.178	0.062	0.031	6.069	84.438
1992	19.122	20.714	33.525	73.396	6.479	2.617	2.932	0.179	0.064	0.030	5.821	85.783
1993	19.835	21.229	33.745	74.836	6.410	2.892	2.908	0.186	0.066	0.031	6.083	87.424
1994	19.909	21.728	34.561	76.256	6.694	2.683	3.028	0.173	0.068	0.036	5.988	89.091
1995	20.089	22.671	34.438	77.259	7.075	3.205	3.101	0.152	0.069	0.033	6.560	91.029
1996	21.002	23.085	35.675	79.785	7.087	3.590	3.157	0.163	0.070	0.033	7.014	94.022
1997	21.445	23.223	36.159	80.873	6.597	3.640	3.105	0.167	0.070	0.034	7.016	94.602
1998	21.656	22.830	36.816	81.369	7.068	3.297	2.927	0.168	0.069	0.031	6.493	95.018
1999	21.623	22.909	37.838	82.427	7.610	3.268	2.963	0.171	0.068	0.046	6.516	96.652
2000	22.580	23.824	38.262	84.731	7.862	2.811	3.008	0.164	0.065	0.057	6.106	98.814
2001	21.914	22.773	38.186	82.902	8.029	2.242	2.622	0.164	0.064	0.070	5.163	96.168
2002	21.904	23.558	38.224	83.747	8.145	2.689	2.701	0.171	0.063	0.105	5.729	97.693
2003	22.321	22.831	38.811	84.014	7.959	2.825	2.807	0.175	0.062	0.115	5.983	97.978
2004	22.466	22.909	40.292	85.805	8.222	2.690	3.010	0.178	0.063	0.142	6.082	100.148
2005	22.797	22.561	40.388	85.790	8.161	2.703	3.116	0.181	0.063	0.178	6.242	100.277
2006	22.447	22.224	39.955	84.687	8.215	2.869	3.276	0.181	0.068	0.264	6.659	99.624
2007	22.749	23.702	39.774	86.251	8.455	2.446	3.502	0.186	0.076	0.341	6.551	101.363
2008	22.385	23.834	37.280	83.540	8.427	2.511	3.852	0.192	0.089	0.546	7.190	99.268
2009	19.692	23.344	35.403	78.415	8.356	2.669	3.899	0.200	0.098	0.721	7.587	94.475
2010	20.817	24.643	35.970	81.425	8.441	2.509	4.295	0.212	0.109	0.924	8.049	98.003

Source:
U.S. Department of Energy, Energy Information Administration, *Monthly Energy Review,* June 2011. Table 1.3, www.eia.doe.gov/emeu/mer/overview.html

Note: NA = Not available.

[a] End-use consumption and electricity net generation.
[b] Natural gas, plus a small amount of supplemental gaseous fuels that cannot be identified separately.
[c] Petroleum products supplied, including natural gas plant liquids and crude oil burned as fuel. Beginning in 1993, also includes ethanol blended into gasoline.
[d] Beginning in 1993, ethanol blended into motor gasoline is included in both "petroleum and "biomass," but is counted only once in total consumption.
[e] Includes coal coke net imports.
[f] Conventional hydroelectric power.
[g] Wood, waste, and alcohol fuels (ethanol blended into motor gasoline).
[h] Includes coal coke net imports and electricity net imports, which are not separately displayed.

Biofuels, which are produced mainly from corn and soybeans, made up 43% of all biomass consumed in the U.S. in 2010. The other 57% comes mainly from waste -- wood waste, municipal solid waste, landfill gas, etc.

Section: INTRODUCTION
Renewable Energy Consumption by Source, 1973-2010
(Trillion Btu)

Year	Hydro-electric Power[a]	Biomass				Geo-thermal[e]	Solar[f]	Wind[g]	Total
		Wood[b]	Waste[c]	Biofuels[d]	Total				
1973	2,861	1,527	2	NA	1,529	20	NA	NA	4,411
1974	3,177	1,538	2	NA	1,540	26	NA	NA	4,742
1975	3,155	1,497	2	NA	1,499	34	NA	NA	4,687
1976	2,976	1,711	2	NA	1,713	38	NA	NA	4,727
1977	2,333	1,837	2	NA	1,838	37	NA	NA	4,209
1978	2,937	2,036	1	NA	2,038	31	NA	NA	5,005
1979	2,931	2,150	2	NA	2,152	40	NA	NA	5,123
1980	2,900	2,474	2	NA	2,476	53	NA	NA	5,428
1981	2,758	2,496	88	13	2,596	59	NA	NA	5,414
1982	3,266	2,510	119	34	2,663	51	NA	NA	5,980
1983	3,527	2,684	157	63	2,904	64	NA	0	6,496
1984	3,386	2,686	208	77	2,971	81	0	0	6,438
1985	2,970	2,687	236	93	3,016	97	0	0	6,084
1986	3,071	2,562	263	107	2,932	108	0	0	6,111
1987	2,635	2,463	289	123	2,875	112	0	0	5,622
1988	2,334	2,577	315	124	3,016	106	0	0	5,457
1989	2,837	2,680	354	125	3,159	162	55	22	6,235
1990	3,046	2,216	408	111	2,735	171	59	29	6,041
1991	3,016	2,214	440	128	2,782	178	62	31	6,069
1992	2,617	2,313	473	145	2,932	179	64	30	5,821
1993	2,892	2,260	479	169	2,908	186	66	31	6,083
1994	2,683	2,324	515	188	3,028	173	68	36	5,988
1995	3,205	2,370	531	198	3,099	152	69	33	6,560
1996	3,590	2,437	577	141	3,155	163	70	33	7,014
1997	3,640	2,371	551	186	3,108	167	70	34	7,016
1998	3,297	2,184	542	202	2,929	168	69	31	6,493
1999	3,268	2,214	540	211	2,965	171	68	46	6,516
2000	2,811	2,262	511	233	3,006	164	65	57	6,106
2001	2,242	2,006	364	254	2,624	164	64	70	5,163
2002	2,689	1,995	402	308	2,705	171	63	105	5,729
2003	2,825	2,002	401	402	2,805	175	62	115	5,983
2004	2,690	2,121	389	487	2,998	178	63	142	6,082
2005	2,703	2,136	403	564	3,104	181	63	178	6,242
2006	2,869	2,109	397	720	3,226	181	68	264	6,659
2007	2,446	2,098	413	978	3,489	186	76	341	6,551
2008	2,511	2,044	436	1,387	3,867	192	89	546	7,190
2009	2,669	1,881	452	1,583	3,915	200	98	721	7,587
2010	2,509	1,986	454	1,870	4,310	212	109	924	8,049

Source:
U.S. Department of Energy, Energy Information Administration, *Monthly Energy Review,* June 2011, Table 10.1, www.eia.doe.gov/emeu/mer/renew.html

Note: NA = Not available.

[a] Conventional hydroelectric power.
[b] Wood, black liquor, and other wood waste.
[c] Municipal solid waste, landfill gas, sludge waste, tires, agricultural byproducts, and other biomass.
[d] Fuel ethanol and biodiesel consumption, plus losses and co-products from the production of ethanol and biodiesel.
[e] Geothermal electricity net generation, heat pump, and direct use energy.
[f] Solar thermal and photovoltaic electricity net generation, and solar thermal direct use energy.
[g] Wind electricity net generation.

Ethanol provided 97% of the renewable transportation fuels consumed in the United States in 2010 while biodiesel accounted for less than 3%. In the industrial sector, biomass accounted for nearly all of the renewable energy consumed.

Section: INTRODUCTION
Renewable Energy Consumption for Industrial and Transportation Sectors, 1973-2010
(Trillion Btu)

	Industrial Sector[a]								Transportation Sector		
		Biomass							Biomass		
Year	Hydro-electric Power[b]	Wood[c]	Waste[d]	Fuel Ethanol[e]	Losses and Co-products[f]	Total	Geo-thermal[g]	Total	Fuel Ethanol[h]	Biodiesel[f]	Total
1973	35	1,165	NA	NA	NA	1,165	NA	1,200	NA	NA	NA
1974	33	1,159	NA	NA	NA	1,159	NA	1,192	NA	NA	NA
1975	32	1,063	NA	NA	NA	1,063	NA	1,096	NA	NA	NA
1976	33	1,220	NA	NA	NA	1,220	NA	1,253	NA	NA	NA
1977	33	1,281	NA	NA	NA	1,281	NA	1,314	NA	NA	NA
1978	32	1,400	NA	NA	NA	1,400	NA	1,432	NA	NA	NA
1979	34	1,405	NA	NA	NA	1,405	NA	1,439	NA	NA	NA
1980	33	1,600	NA	NA	NA	1,600	NA	1,633	NA	NA	NA
1981	33	1,602	87	0	6	1,695	NA	1,728	7	NA	7
1982	33	1,516	118	0	16	1,650	NA	1,683	18	NA	18
1983	33	1,690	155	0	29	1,874	NA	1,908	34	NA	34
1984	33	1,679	204	1	35	1,918	NA	1,951	41	NA	41
1985	33	1,645	230	1	42	1,918	NA	1,951	50	NA	50
1986	33	1,610	256	1	48	1,915	NA	1,948	57	NA	57
1987	33	1,576	282	1	55	1,914	NA	1,947	66	NA	66
1988	33	1,625	308	1	55	1,989	NA	2,022	67	NA	67
1989	28	1,584	200	1	56	1,841	2	1,871	68	NA	68
1990	31	1,442	192	1	49	1,684	2	1,717	60	NA	60
1991	30	1,410	185	1	56	1,652	2	1,684	70	NA	70
1992	31	1,461	179	1	64	1,705	2	1,737	80	NA	80
1993	30	1,484	181	1	74	1,741	2	1,773	94	NA	94
1994	62	1,580	199	1	82	1,862	3	1,927	105	NA	105
1995	55	1,652	195	2	86	1,934	3	1,992	112	NA	112
1996	61	1,683	224	1	61	1,969	3	2,033	81	NA	81
1997	58	1,731	184	1	80	1,996	3	2,057	102	NA	102
1998	55	1,603	180	1	86	1,872	3	1,929	113	NA	113
1999	49	1,620	171	1	90	1,882	4	1,934	118	NA	118
2000	42	1,636	145	1	99	1,881	4	1,928	135	NA	135
2001	33	1,443	129	3	108	1,681	5	1,719	141	1	142
2002	39	1,396	146	3	130	1,676	5	1,720	168	2	170
2003	43	1,363	142	4	169	1,679	3	1,726	228	2	230
2004	33	1,476	132	6	203	1,817	4	1,853	286	3	290
2005	32	1,452	148	7	230	1,837	4	1,873	327	12	339
2006	29	1,472	130	10	285	1,897	4	1,930	442	33	475
2007	16	1,413	144	10	377	1,944	5	1,964	557	46	602
2008	17	1,344	144	12	532	2,031	5	2,053	786	40	826
2009	18	1,198	154	13	617	1,982	4	2,005	894	40	934
2010	16	1,307	168	16	738	2,229	4	2,249	1,070	28	1,098

Source:
U.S. Department of Energy, Energy Information Administration, *Monthly Energy Review*, June 2011, Table 10.2b, www.eia.doe.gov/emeu/mer/renew.html

Note: NA = Not available.

[a] Industrial sector fuel use, including that at industrial combined-heat-and-power (CHP) and industrial electricity plants.
[b] Conventional hydroelectric power.
[c] Wood, black liquor, and other wood waste.
[d] Municipal solid waste, landfill gas, sludge waste, tires, agricultural byproducts, and other biomass.
[e] Ethanol blended into motor gasoline.
[f] Losses and co-products from the production of fuel ethanol and biodiesel. Does not include natural gas, electricity, and other non-biomass energy used in the production of fuel ethanol and biodiesel—these are included in the industrial sector consumption statistics for the appropriate energy source.
[g] Geothermal heat pump and direct use energy.
[h] The ethanol portion of motor fuels (such as E10 and E85) consumed by the transportation sector.

In 2010, biomass accounted for about 76% of the renewable energy used in the residential sector and about 85% of the renewable energy used in the commercial sector.

Section: INTRODUCTION
Renewable Energy Consumption for Residential and Commercial Sectors, 1973-2010
(Trillion Btu)

	Residential Sector				Commercial Sector[a]						
	Biomass					Biomass					
Year	Wood[b]	Geo-thermal[c]	Solar[d]	Total	Hydro-electric	Wood[b]	Waste[e]	Fuel Ethanol	Total	Geo-thermal[c]	Total
1973	354	NA	NA	354	NA	7	NA	NA	7	NA	7
1974	371	NA	NA	371	NA	7	NA	NA	7	NA	7
1975	425	NA	NA	425	NA	8	NA	NA	8	NA	8
1976	482	NA	NA	482	NA	9	NA	NA	9	NA	9
1977	542	NA	NA	542	NA	10	NA	NA	10	NA	10
1978	622	NA	NA	622	NA	12	NA	NA	12	NA	12
1979	728	NA	NA	728	NA	14	NA	NA	14	NA	14
1980	850	NA	NA	850	NA	21	NA	NA	21	NA	21
1981	870	NA	NA	870	NA	21	NA	0	21	NA	21
1982	970	NA	NA	970	NA	22	NA	0	22	NA	22
1983	970	NA	NA	970	NA	22	NA	0	22	NA	22
1984	980	NA	NA	980	NA	22	NA	0	22	NA	22
1985	1010	NA	NA	1010	NA	24	NA	0	24	NA	24
1986	920	NA	NA	920	NA	27	NA	0	27	NA	27
1987	850	NA	NA	850	NA	29	NA	1	30	NA	30
1988	910	NA	NA	910	NA	32	NA	1	33	NA	33
1989	920	5	52	977	1	76	22	1	99	3	102
1990	580	6	56	641	1	66	28	0	94	3	98
1991	610	6	57	673	1	68	26	0	95	3	100
1992	640	6	59	706	1	72	32	0	105	3	109
1993	550	7	61	618	1	76	33	0	109	3	114
1994	520	6	63	589	1	72	35	0	106	4	112
1995	520	7	64	591	1	72	40	0	113	5	118
1996	540	7	65	612	1	76	53	0	129	5	135
1997	430	8	64	502	1	73	58	0	131	6	138
1998	380	8	64	452	1	64	54	0	118	7	127
1999	390	9	63	461	1	67	54	0	121	7	129
2000	420	9	60	489	1	71	47	0	119	8	128
2001	370	9	59	438	1	67	25	0	92	8	101
2002	380	10	57	448	0	69	26	0	95	9	104
2003	400	13	57	470	1	71	29	1	101	11	113
2004	410	14	57	481	1	70	34	1	105	12	118
2005	430	16	58	504	1	70	34	1	105	14	119
2006	390	18	63	472	1	65	36	1	102	14	117
2007	430	22	70	522	1	69	31	2	102	14	118
2008	450	26	80	556	1	73	34	2	109	15	125
2009	430	33	89	552	1	72	36	3	112	17	129
2010	420	37	97	554	1	70	34	3	108	19	127

Source:
U.S. Department of Energy, Energy Information Administration, *Monthly Energy Review*, June 2011, Table 10.2a, www.eia.doe.gov/emeu/mer/renew.html

Note: NA = Not available.

[a] Commercial sector fuel use, including that at commercial combined-heat-and-power (CHP) and commercial electricity-only plants.
[b] Wood, black liquor, and other wood waste.
[c] Geothermal heat pump and direct use energy.
[d] Solar thermal direct use energy and photovoltaic electricity generation. Small amounts of commercial sector are included in the residential sector.
[e] Municipal solid waste, landfill gas, sludge waste, tires, agricultural byproducts, and other biomass.

Total industrial biomass energy consumption was approximately 2,031 trillion Btu in 2008. The bulk of industrial biomass energy consumption is derived from forestlands (lumber, paper and allied products); more than one-half of this total is black liquor – a pulping mill by-product containing unutilized wood fiber and chemicals. Black liquor is combusted in recovery boilers to recover valuable chemicals and to produce heat and power. Wood and wood wastes generated in primary wood processing mills account for another third of total industrial biomass energy consumption. The data contained in this table are from a survey of manufacturers that is conducted every four years by the EIA.

Section: INTRODUCTION

Industrial Biomass Energy Consumption and Electricity Net Generation by Industry and Energy Source, 2008

		Biomass Energy Consumption (Trillon Btus)			
Industry	**Energy Source**	**Total**	**For Electricity**	**For Useful Thermal Output**	**Net Generation (Million Kilowatthours)**
Total	**Total**	**2,031.193**	**183.953**	**1,847.240**	**27,462**
Agriculture, Forestry, and Mining	**Total**	**16.159**	**1.231**	**14.928**	**229**
	Agricultural Byproducts/Crops	16.159	1.231	14.928	229
Manufacturing	**Total**	**1,908.531**	**182.721**	**1,725.810**	**27,233**
Food and Kindred Industry Products	**Total**	**21.328**	**0.631**	**20.697**	**107**
	Agricultural Byproducts/Crops	15.819	0.160	15.659	33
	Other Biomass Gases	0.289	0.095	0.194	7
	Other Biomass Liquids	0.044	0.044	-	5
	Sludge Waste	0.243	0.055	0.188	8
	Wood/Wood Waste Solids	4.933	0.277	4.657	54
Lumber	**Total**	**225.729**	**10.682**	**215.047**	**1,287**
	Sludge Waste	0.052	0.006	0.046	1
	Wood/Wood Waste Solids	225.676	10.676	215.001	1,286
Paper and Allied Products	**Total**	**1,116.304**	**170.909**	**945.396**	**25,774**
	Agricultural Byproducts/Crops	1.335	0.036	1.300	5
	Black Liquor	787.380	112.361	675.019	17,152
	Landfill Gas	0.034	0.004	0.029	1
	Other Biomass Gases	0.183	0.015	0.168	3
	Other Biomass Liquids	0.122	0.015	0.107	3
	Other Biomass Solids	9.477	1.762	7.715	326
	Sludge Waste	4.083	0.937	3.147	160
	Wood/Wood Waste Liquids	2.510	0.383	2.127	73
	Wood/Wood Waste Solids	311.180	55.395	255.785	8,050
Chemicals and Allied Products	**Total**	**4.319**	**0.152**	**4.167**	**28**
	Other Biomass Liquids	0.061	0.005	0.056	1
	Sludge Waste	0.305	0.043	0.261	9
	Wood/Wood Waste Solids	3.953	0.104	3.849	18
Biorefineries	**Total**	**532.042**	**-**	**532.042**	**-**
	Biofuels Losses and Coproducts[c]	532.042	-	532.042	-
	Biodiesel Feedstock	1.195	-	1.195	-
	Ethanol Feedstock	530.847	-	530.847	-
Other[a]	**Total**	**8.810**	**0.349**	**8.461**	**37**
Nonspecified[b]	**Total**	**106.502**	**-**	**106.502**	**-**
	Ethanol[d]	11.652	-	11.652	-
	Landfill Gas	92.233	-	92.233	-
	Municipal Solid Waste Biogenic[e]	2.617	-	2.617	-

Source:

U.S. Department of Energy, Energy Information Administration, *Renewable Energy Annual* , 2008, Washington, D.C., Table 1.8, http://www.eia.doe.gov/cneaf/solar.renewables/page/rea_data/table1_8.html

Note: Totals may not equal sum of components due to independent rounding.
= Not Applicable.

[a]Other includes Apparel; Petroleum Refining; Rubber and Misc. Plastic Products; Transportation Equipment; Stone, Clay, Glass, and Concrete Products; Furniture and Fixtures; and related industries.

[b]Primary purpose of business is not specified.

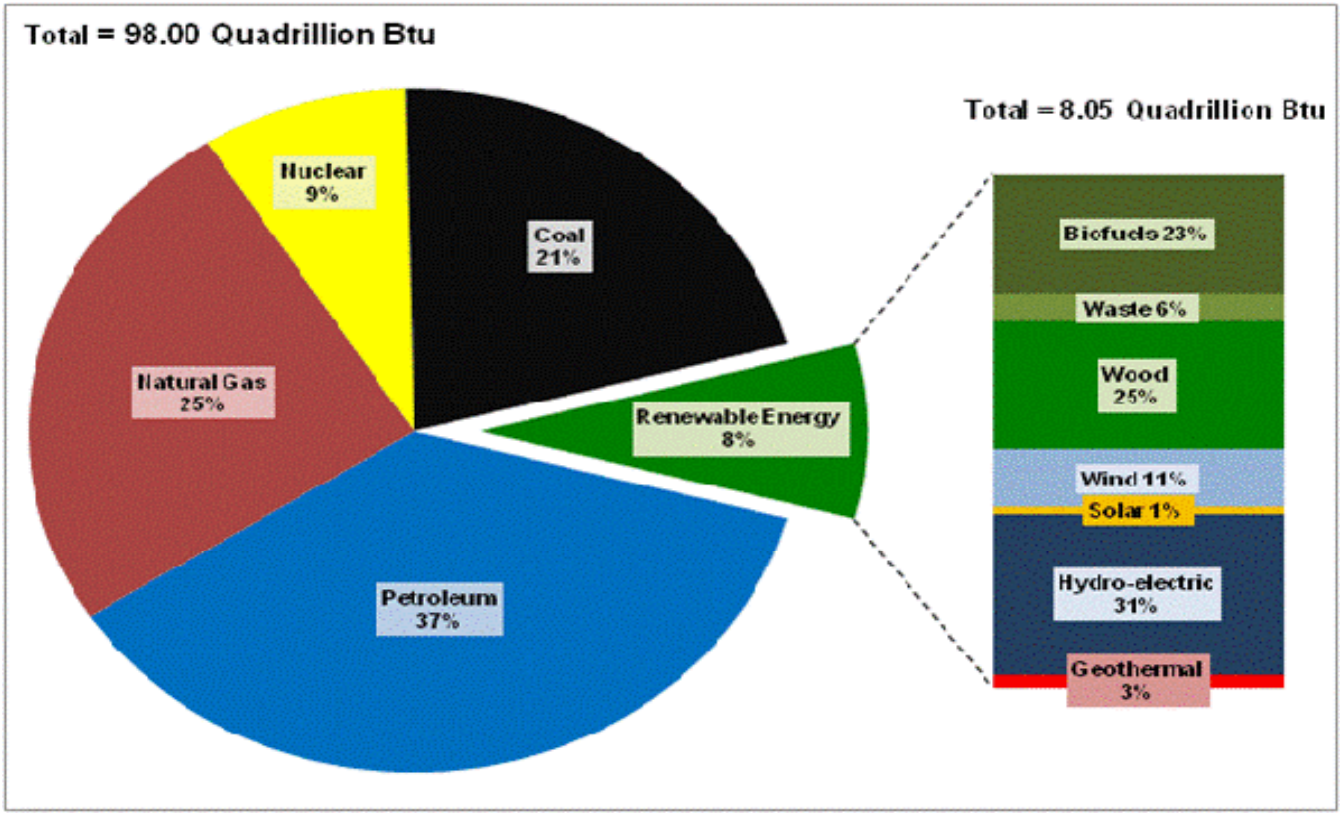
[c]Losses and coproducts from production of biodiesel and ethanol.

[d]Ethanol primarily derived from corn minus denaturant.

[e]Includes paper and paper board, wood, food, leather, textiles and yard trimmings.

Biomass is the single largest source of renewable energy in the United States. Biomass, which includes biofuels, waste and woody materials, surpassed hydroelectric power in 2005 and by 2010 accounted for over half of all renewable energy consumption. In 2010, biomass contributed about 4.4% of the total U.S. energy consumption of 98 quadrillion Btu. Wood, wood waste, and black liquor from pulp mills is the single largest source, accounting for almost one-half of total biomass energy consumption. Wastes (which include municipal solid waste, landfill gas, sludge waste, straw, agricultural by-products, and other secondary and tertiary sources of biomass) accounts for 11% of total biomass consumption. The remaining share is alcohol fuel derived principally from corn grain.

Section: INTRODUCTION
Summary of Biomass Energy Consumption, 2010



Source:
U.S. Department of Energy, Energy Information Administration, *Monthly Energy Review*, July 2011, Table 1.3, *Primary Energy Consumption by Source,* and Table 10.1, *Renewable Energy Production and* Consumption *by Source*.
http://www.eia.doe.gov/emeu/mer/contents.html

Sustainability

Sustainability can be defined as the ability of an activity to meet the needs of the present without compromising the ability of future generations to meet their own needs (Bruntland, 1987). The potential for bioenergy to be a more sustainable source of liquid fuel, electric power, and heat than current dominant sources is the major driver behind policies that support bioenergy research and development. Sustainability comprises overlapping environmental, economic, and social aspects. Tools to assess sustainability include indicators and life-cycle analyses. Sustainability of bioenergy can be assessed at scales ranging from individual operations (e.g., a farm or biorefinery) to industries (e.g., soybean biodiesel or mixed-feedstock cellulosic ethanol) of regional, national, or global extent. Assessments of sustainability must consider effects throughout the supply chain, even when focusing on a single operation within that chain. (For example, the concept of spatial footprints can be used to incorporate aspects of land-use efficiency in feedstock production when assessing the sustainability of biorefineries.)

Although usage of the term varies, the ability of a particular system to persist over time can be called “viability” and is one aspect of sustainability. Long-term profitability is the most obvious aspect of viability. However, viability has environmental and social as well as economic components. For example, viability of plant-based feedstock production requires the maintenance of soil quality, and bioenergy systems in general require acceptance from the public.

In addition to viability, sustainability encompasses the extent to which a particular system contributes to the ability of a broader system – a region, a country, or the globe – to meet its present and future needs. Environmental considerations for the sustainability of a bioenergy system include effects on soil quality, water quality and quantity, greenhouse gas (GHG) balance, air quality, biodiversity, and productivity. Social and economic considerations overlap and include employment, welfare, international trade, energy security, and natural resource accounts, in addition to profitability and social acceptability.

Indicators can be used to assess the sustainability of bioenergy systems. Sustainability indicators can be defined as any measurable quantity that provides information about potential or realized effects of human activities on environmental, social, or economic phenomena of concern. Indicators can relate to management practices (e.g., amount of fertilizer applied) or to their effects (e.g., nutrients in soil or in waterways). Indicators based on management practices can be useful in certification systems, such as those under development by the Roundtable for Sustainable Biofuels and the Council on Sustainable *Biomass* Production. Indicators that measure effects can be used to provide an empirical grounding for the interpretation of management-based indicators or to assess the overall sustainability of a bioenergy industry or pathway. To the extent possible, indicators should reflect the entire supply chain. Such indicators can provide guidance for decisions such as choosing a specific conversion technology or choosing locations that are both suitable for low-cost feedstock production as well as close to markets.

Life-cycle analyses (LCAs) are another tool used to assess bioenergy sustainability. An LCA typically considers one or more quantities of environmental significance (e.g., energy consumption, C_{eq} emissions, consumptive water use) and sums the contribution to that quantity (negative as well as positive) from each step of the entire supply chain ("cradle to grave"). LCAs can seem straightforward on the surface, but LCAs measuring similar quantities can give disparate results depending on how system boundaries, baseline conditions, and co-products are defined and dealt with.

More generally, different approaches to system boundaries, baseline conditions, and co-products pose challenges to any effort to assess the sustainability of bioenergy systems. The treatment of baseline conditions is particularly problematic. The term "baseline" can describe conditions that exist prior to the implementation of bioenergy production, or it can describe the most likely alternative uses of the land and resources. The former type of baselines can potentially be measured. In some cases, the latter type of baselines can be approximated by carefully selecting and monitoring land resources that are similar except lacking bioenergy systems. In other cases, especially when assessing effects that may be geographically dispersed (e.g., air pollution or energy security), suitable proxy sites may not exist for those latter baselines, and alternate scenarios must be projected through simulation modeling.

A full understanding of the relative sustainability of a bioenergy system requires comparing the effects of that system to the effects of displaced or alternative sources of energy. This comparison may or may not be considered an issue of baselines. Typically, bioenergy systems are compared against fossil fuel systems (such as production of electricity from coal or liquid fuels from petroleum). The sustainability of fossil fuel systems should be considered in sustainability assessments, including advantages such as pre-existing infrastructure and disadvantages such as non-renewability, high GHG emissions, adverse health impacts, and (in the case of oil) frequent location of resources in politically unstable regions. Comparisons between bioenergy and other renewable energy technologies are also appropriate in some situations, particularly when the desired end product is electricity.

A central controversy regarding the sustainability of bioenergy concerns the idea of indirect land-use change (iLUC). Given certain assumptions, economic models predict that bioenergy production could raise global agricultural commodity prices, inducing the conversion of forests and grasslands to bioenergy production. Researchers disagree about whether these models are sufficiently realistic, valid, and/or based on accurate input data for use in policymaking. This topic is explored more fully in "Indirect Land-Use Change – The Issues" found in the feedstock section.

Although researchers disagree about whether and to what extent current bioenergy systems are sustainable, there is relatively broad agreement that bioenergy has at least the potential to be more sustainable than currently dominant energy systems. For example, many researchers believe that the most pressing concerns about current bioenergy sustainability could be addressed by growing lignocellulosic biomass crops

such as switchgrass, Miscanthus, or hybrid poplar on land that is degraded, abandoned, or ill-suited to growing traditional crops. Such a plan will require advances both in technology (e.g., to overcome the recalcitrance of lignocellulose) and in policy (e.g., the widespread adoption of sound standards for sustainability). Despite daunting challenges, research progresses on both fronts.

Works cited:

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Further reading:

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Pickett, J., Anderson, D., Bowles, D., Bridgwater, T., Jarvis, P., Mortimer, N., Poliakoff, M., Woods, J., 2008. Sustainable biofuels: prospects and challenges. The Royal Society. Online at: http://royalsociety.org/Sustainable-biofuels-prospects-and-challenges/

Written by: Allen McBride, Oak Ridge Institute for Science and Education, September 2011.

Indirect Land-Use Change – The Issues

A central controversy regarding the sustainability of bioenergy concerns the idea of indirect land-use change (iLUC). With respect to bioenergy, we can define iLUC as any land-use change caused by bioenergy production, excluding the conversion of land used directly for that production. The central hypothesis behind iLUC concerns is that when land used for a given purpose is converted to bioenergy feedstock production, then land used for the original purpose will be more scarce, increasing the value of such land and inducing people to convert other land to that purpose. For example, if an acre of land used to grow corn for livestock feed is converted to growing corn for ethanol, then it would be assumed that the price of feed corn would increase by approximately the amount required to induce someone else to convert an acre of land from some other purpose to producing corn for feed. Furthermore, if this land to be converted to feed corn production has high carbon stocks (e.g., old-growth forest), then the conversion will release CO_2 to the atmosphere, creating a carbon debt that could take decades to pay off via offset fossil fuel combustion. Under certain simple assumptions, scenarios such as this must occur. For example, attempts to quantify GHG emissions from bioenergy iLUC are guaranteed to produce positive results if researchers use models that assume that:

- all agricultural land available for conversion is fully utilized,
- all non-agricultural land available for conversion is relatively undisturbed and has high carbon stores,
- all land available for conversion is privately held,
- all landowners seek to maximize profit, and
- increases in bioenergy production occur suddenly (i.e., act as economic "shocks").

However, these assumptions do not hold in many areas of the world. Because modeling requires generalizations, assumptions will inevitably be violated to some degree. These violations are acceptable only when correcting them would not greatly affect results. In the case of iLUC, conceptual models suggest that correcting some of these assumptions in simulation models could fundamentally change conclusions about iLUC. For example, at the margins of rainforests, land-use change may be driven by multi-year cycles of shifting cultivation, including low-profit and GHG-intensive slash-and-burn techniques. In addition, new deforestation may be driven in part by the desire to claim effectively ungoverned land. Increased commodity prices could plausibly provide incentives for farmers in these areas to more sustainably and intensively manage already-cleared land instead of abandoning it to clear secondary or primary forest.

Unfortunately, data may not currently exist to allow iLUC simulations that would take such potentially crucial mechanisms into account. More research is needed to collect such data, including better resolution land-use and land-cover data throughout the world, and surveys of land managers to better understand motivations for management decisions. In addition to better data, more work is needed to integrate existing but difficult-to-reconcile data sets, such as those with high spatial but low temporal resolution and vice-versa. Techniques of causal analysis pioneered in epidemiology

hold promise for the challenge of determining whether bioenergy plays a significant market-mediated role in deforestation and other land-use change.

Researchers disagree about whether potential iLUC effects should be considered in policymaking. Because some models predict large GHG emissions from iLUC, some researchers argue that not considering iLUC effects would be an unacceptable risk. Other researchers argue that the uncertainty surrounding current estimates of iLUC, both in terms of differing estimates from current models as well as the lack of empirical validation of those models, is too large to consider their results in policymaking. In addition, some researchers argue that considering iLUC effects of bioenergy systems in policymaking is inappropriate because analogous indirect land-use change effects of fossil fuel exploration, extraction, and use are poorly understood and are not taken into account in estimates of environmental and socioeconomic effects of fossil fuels. Finally, there is philosophical debate about how to apportion “blame” (e.g., carbon penalties) among multiple causal factors leading to a given outcome. For example, if certain indirect deforestation would not have occurred in the absence of a biofuel system, then the same could also be said of the individuals or groups actually burning or cutting that forest.

Further reading:

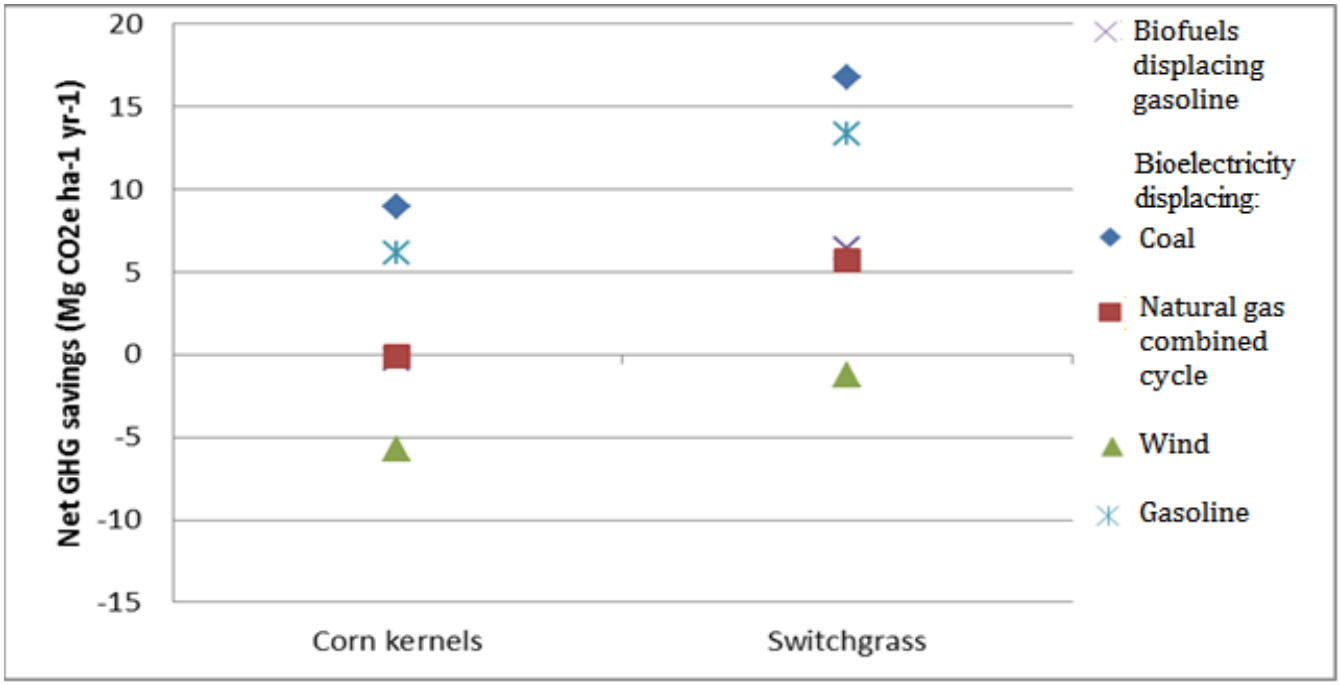
Fritsche, U. R., Sims, R. E. H. and Monti, A., 2010. Direct and indirect land-use competition issues for energy crops and their sustainable production – an overview. Biofuels, Bioproducts and Biorefining, 4: 692–704. Online at: http://onlinelibrary.wiley.com/doi/10.1002/bbb.258/full

Kline, K., Dale, V.H., Lee, R., Leiby, P., 2009. In defense of biofuels, done right. Issues Sci. Technol. 25, 75-84. Online at: http://www.issues.org/25.3/kline.html

Greenhouse gas emissions are one of the many factors used in comparing the sustainability level of various energy sources. Greenhouse emissions from fossil fuels are generally greater than emissions from biomass derived fuels. However biomass fuels can also vary greatly with respect to levels of greenhouse gas emissions depending on the biomass resource used, how those resources were produced or collected, and the biomass to energy conversion technology pathway. One way of obtaining a sense of the difference in emissions between fossil fuels and various biomass energy technology pathways is to evaluate net greenhouse gas savings based on which fossil fuel source is being displaced. Such an evaluation has been recently performed comparing corn grain and switchgrass as the biomass feedstock for production of liquid transportation fuels, electric transportation, and electricity for other uses.

Section: INTRODUCTION

A Comparison of Climate Impacts of Various Bioenergy Systems



This figure (from Lemoine et al 2010) shows that net GHG savings per area of cropland are sensitive to assumptions about which fossil fuel technology is being displaced. The X marker shows ethanol displacing gasoline. The blue asterik follows a study by Campbell et al (2009) in assuming that bioelectricity is used to power electrified vehicles and displaces gasoline. The diamond, square, and triangle (coal, natural gas combined cycle, and wind electricity) show the GHG benefit (or cost) when bioelectricity displaces each of these types of power. Corn grain production is assumed to have an indirect land use effect of 30g CO2e (MJ ethanol)-1 while switchgrass is assumed to be planted on Conservation Reserve Land with no indirect land use effect but also no soil carbon sequestration.

Sources:

Lemoine, D.M. et al. The Climate Impacts of Bioenergy Systems Depend on Market and Regulatory Policy Contexts. Environmental Science & Technology 44:7347-7350

Campbell, J.E.; Lobel, D.B.; Field, C.B. Greater transportation energy and GHG offsets from bioelectricity than ethanol. Science 2009, 324, 1055-1057.

Supplementary material including a complete description of the Energy Displacement Model is available free of charge at http://pubs.acs.org.

Biomass Resources Overview

Biomass Resources include all plant and plant-derived (organic) materials that are available on a renewable or recurring basis. Plant biomass is a complex mixture of organic materials, primarily carbohydrates (~75% dry weight) and lignin (~25% dry weight) with the proportions varying by plant type, but also containing fats, proteins and minerals. The carbohydrates consist mainly of cellulose or hemicellulose fibers which give strength to plant structures with a small portion of carbohydrates in the form of starches and simple sugars. Lignin is the glue that holds the fibers together. Thus the stems, stalks, branches, and leaves of plants are the lignocellulosic components of plants which are eaten by forage animals for food, processed mechanically for bioproducts (such as wood used in buildings or furniture), or processed thermally or biochemically in many different ways to produce heat, electricity, chemicals, and biofuels. Both the primary lignocellulosic resources (trees, grasses, and stalks of food crops) and all by-products of processing (from pulping black liquor to sawdust to food waste and manure) compose the biomass resource base that can be utilized for producing various types of bioenergy. For production of liquid biofuels, some processes involve separating the lignin from the cellulose and hemicellulose in order to gain access to the carbohydrates that can be broken down into sugars. Reduction of lignocellulosic materials to sugars and other compounds is anticipated to be the major source of liquid biofuels and chemicals in the future. Examples of biomass resources that are currently used for liquid biofuels include: starches from the grain of corn (maize), wheat and other grains; sugars squeezed from the stalks of sugarcane; and oils derived from soybeans and other oilseed crops.

All biomass resources available for producing bioenergy and biofuels are expected to be produced and harvested in a sustainable manner. A recent analysis of biomass resources (US Department of Energy, 2011), includes a more rigorous treatment and modeling of resource sustainability than was done in a previous evaluation (Perlack et al. 2005). The 2011 update evaluates two scenarios—baseline and high yield. Overall, results of this update are consistent with the 2005 study in terms of the magnitude of the resource potential previously estimated to be over one billion dry tons on an annual basis.

In the 2011 baseline scenario, forest resource quantities are estimated to vary from about 33 to 119 million dry tons currently to about 35 to 129 million dry tons in 2030 over a price range of ($20-$80 per dry ton). Primary forest biomass (derived from logging, thinnings, and land clearing) is the single largest source of forest resource. The agricultural resources show considerably more supply, with the quantity increasing significantly over time. This increase is due to yield growth (assumed to be about 1% per year) and assumptions of more land managed with no-till or reduced cultivation, all of which makes more crop residue available. The increase can also be attributed to the deployment of energy crops, which are assumed to be first planted in 2014 and have yield growth of 1% per year that is due to breeding and selection and experience gained). In 2012, biomass supplies are estimated to range from about 59 million dry tons at a *farmgate price of $40 per dry ton or less to 162 million dry tons at $60 per dry ton.

The composition of this biomass is about two-thirds crop residue and one-third various agricultural processing residues and wastes. By 2030, quantities increase to 160 million dry tons at the lowest simulated price to 664 million dry tons at the highest simulated price ($60 per dry ton). At prices above $50 per dry ton, energy crops become the dominant resource after 2022.

No high-yield scenario was evaluated for forest resources except for the woody crops. Forest residues come from existing timberlands, and there is no obvious way to increase volumes other than reducing the amounts of residues retained onsite for environmental sustainability or decreasing the merchantable utilization requirements—neither option was considered. Forest residues and wastes total to 100 million dry tons by 2022.

The high-yield agriculture scenario assumes a greater proportion of corn in reduced and no-till cultivation and increased corn yields (averaging 2% per year) to about double the current rate of annual increase, all factors which increase residue levels. Agricultural residues and wastes are about 244 million dry tons currently and increase to 404 million dry tons by 2030 at a farmgate price of $60 per dry ton. For energy crops, the high-yield scenario increased the annual rate of crop productivity growth from the 1% baseline to 2%, 3%, and 4% annually. Energy crops are the largest potential source of biomass feedstock, with

potential energy crop supplies varying considerably depending on what is assumed about productivity. At a 2% annual growth rate, energy crop potential is 540 million dry tons by 2030 and 658 million dry tons if an annual increase in productivity of 3% is assumed. Both of these estimates assume a farmgate price of $60 per dry ton. Increasing yield growth to 4% pushes the energy crop potential to nearly 800 million dry tons. Energy crops become very significant in the high-yield scenario—providing over half of the potential biomass.

In total, potential supplies at a forest roadside or farmgate priceof $60 per dry ton range from 855 to 1009 million dry tons by 2022 and from about 1046 to 1305 million dry tons by 2030, depending on what is assumed about energy crop productivity (2% to 4% annual increase over current yields). This estimate does not include resources that are currently being used, such as corn grain and forest products industry residues. By including the currently used resources, the total biomass estimate jumps to well over one billion dry tons and to over 1.6 billion dry tons with more aggressive assumptions about energy crop productivity.

The above results, along with estimates of currently used resources are summarized in the Data Book table entitled "Summary of Currently Used and Potential Biomass." One important year highlighted in this table is 2022—the year in which the revised Renewable Fuels Standard (RFS) mandates the use of 36 billion gallons per year (BGY) of renewable fuels (with 20 billion gallons coming from cellulosic biofuels). The feedstock shown in the baseline scenario accounts for conventional biofuels (corn grain, ethanol, and biodiesel) and shows 602 million dry tons of potential lignocellulosic biomass resource. This potential resource is more than sufficient to provide feedstock to produce the required 20 billion gallons of cellulosic biofuels. The high-yield scenario demonstrates a potential that far exceeds the RFS mandate.

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* The farmgate price is a basic feedstock price that includes cultivation (or acquisition), harvest, and delivery of biomass to the field edge or roadside. It excludes on-road transport, storage, and delivery to an end user. For grasses and residues this price includes baling. For forest residues and woody crops this includes minimal comminution (e.g. chipping).

Sources:

Perlack RD, Wright LL, Turhollow AF, Graham RL, Stokes BJ, Erbach DC. 2005. Biomass as feedstock for a bioenergy and bioproducts industry: the technical feasibility of a billion-ton annual supply. DOE/GO-102995-2135 or ORNL/TM-2005/66. Oak Ridge National Laboratory, Oak Ridge, TN. 60 pp. www1.eere.energy.gov/biomass/publications.html

U.S. Department of Energy. 2011. U.S. Billion-Ton Update: Biomass Supply for a Bioenergy and Bioproducts Industry. R.D. Perlack and B.J. Stokes (Leads), ORNL/TM-2010/224. Oak Ridge National Laboratory, Oak Ridge, TN p.227. (accessed 8-15-2011 at https://bioenergykdf.net/content/billiontonupdate)

Biomass Definitions in Legislation

Biomass has been referenced in legislation for over 30 years. Definitions of biomass have evolved over time, mostly since 2004. A recent report by the Congressional Research Service provides a comprehensive review of fourteen biomass definitions found in recent enacted legislation. Seven definitions in pending legislation are also reviewed. Comments on similarities and differences among the definitions are provided and issues for biomass feedstock development related to differences in definitions are discussed. Definitions from the two most recent pieces of enacted legislation were extracted from the report. A key difference regards the inclusion or non-inclusion of biomass harvested from federal land. It is highly recommended that the full report be accessed to understand the implications of the various biomass definitions found in legislation.

In the Food, Conservation, and Energy Act of 2008 (2008 farm bill, P.L. 110-246) Title IX, Sec. 9001(12) the term "renewable biomass" means--

A) materials, pre-commercial thinnings, or invasive species from National Forest System land and public lands (as defined in section 103 of the Federal Land Policy and Management Act of 1976 (43 U.S.C. 1702)) that—(i) are byproducts of preventive treatments that are removed—(I) to reduce hazardous fuels; (II) to reduce or contain disease or insect infestation; or (III) to restore ecosystem health; (ii) would not otherwise be used for higher-value products; and (iii) are harvested in accordance with—(I) applicable law and land management plans; and (II) the requirements for—(aa) old-growth maintenance, restoration, and management direction of paragraphs (2), (3), and (4) of subsection (e) of section 102 of the Healthy Forests Restoration Act of 2003 (16 U.S.C. 6512); and (bb) large-tree retention of subsection (f) of that section; or

(B) any organic matter that is available on a renewable or recurring basis from non-Federal land or land belonging to an Indian or Indian tribe that is held in trust by the United States or subject to a restriction against alienation imposed by the United States, including—(i) renewable plant material, including—(I) feed grains; (II) other agricultural commodities; (III) other plants and trees; and (IV) algae; and (ii) waste material, including—(I) crop residue; (II) other vegetative waste material (including wood waste and wood residues); (III) animal waste and byproducts (including fats, oils, greases, and manure); and (IV) food waste and yard waste.

In the Energy Independence and Security Act of 2007 (EISA, P.L. 110-140) Title II, Sec. 201(1)(I) the term "renewable biomass" means each of the following:

(i) Planted crops and crop residue harvested from agricultural land cleared or cultivated at any time prior to the enactment of this sentence that is either actively managed or fallow, and nonforested.

(ii) Planted trees and tree residue from actively managed tree plantations on non-federal land cleared at any time prior to enactment of this sentence, including land belonging to an Indian tribe or an Indian individual, that is held in trust by the United States or subject to a restriction against alienation imposed by the United States.

(iii) Animal waste material and animal byproducts.

(iv) Slash and pre-commercial thinnings that are from non-federal forestlands, including forestlands belonging to an Indian tribe or an Indian individual, that are held in trust by the United States or subject to a restriction against alienation imposed by the United States, but not forests or forestlands that are ecological communities with a global or State ranking of critically imperiled, imperiled, or rare pursuant to a State Natural Heritage Program, old growth forest, or late successional forest.

(v) Biomass obtained from the immediate vicinity of buildings and other areas regularly occupied by people, or of public infrastructure, at risk from wildfire.

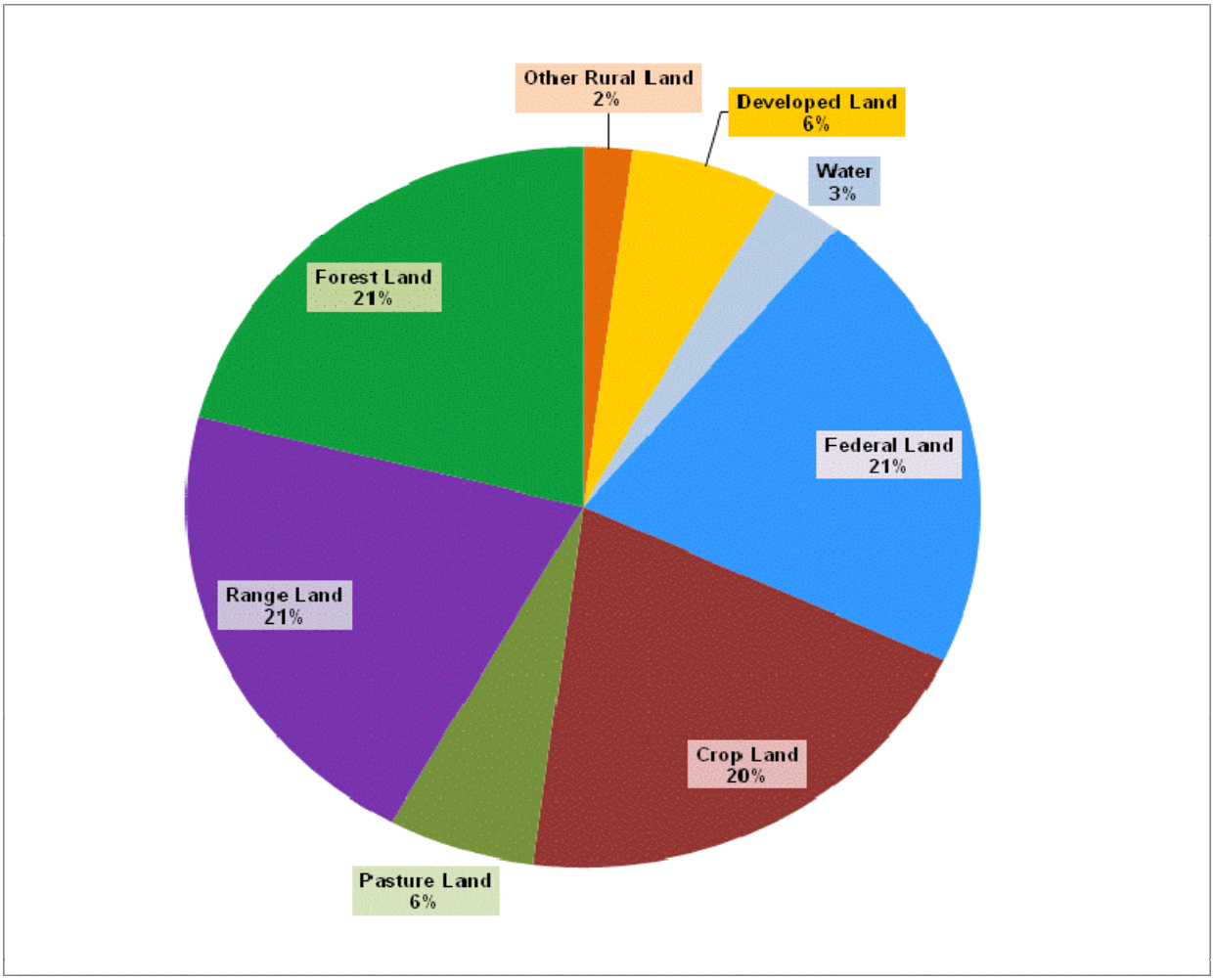
(vi) Algae.

(vii) Separated yard waste or food waste, including recycled cooking and trap grease.

Source: Bracmort K. and Gorte, Ross W. *Biomass: Comparison of Definitions in Legislation Through the 111th Congress.* Congressional Research Service. October 8, 2010. 21 p.

In 2007, the United States had a total surface area of 1,938 million acres. Based on the 2007 Natural Resources Inventory, 20% is classified as crop land and 21% was classified as forest land which shows that nearly half of the land area in the U.S. is well suited for either biomass crops or biomass residuals. Pasture land and Range land is for the most part, too dry to provide large quantities of biomass material. Developed land is a potential source for post-consumer biomass residuals like those found in municipal solid waste landfills.

Major Uses of Land in the United States, 2007

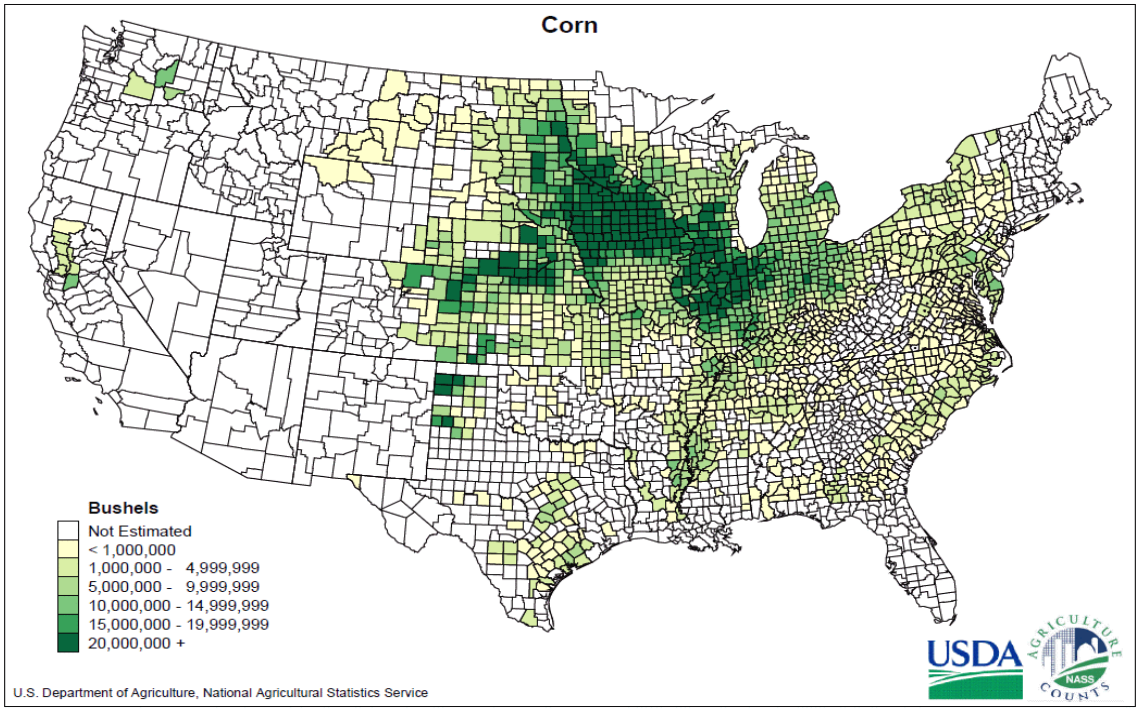


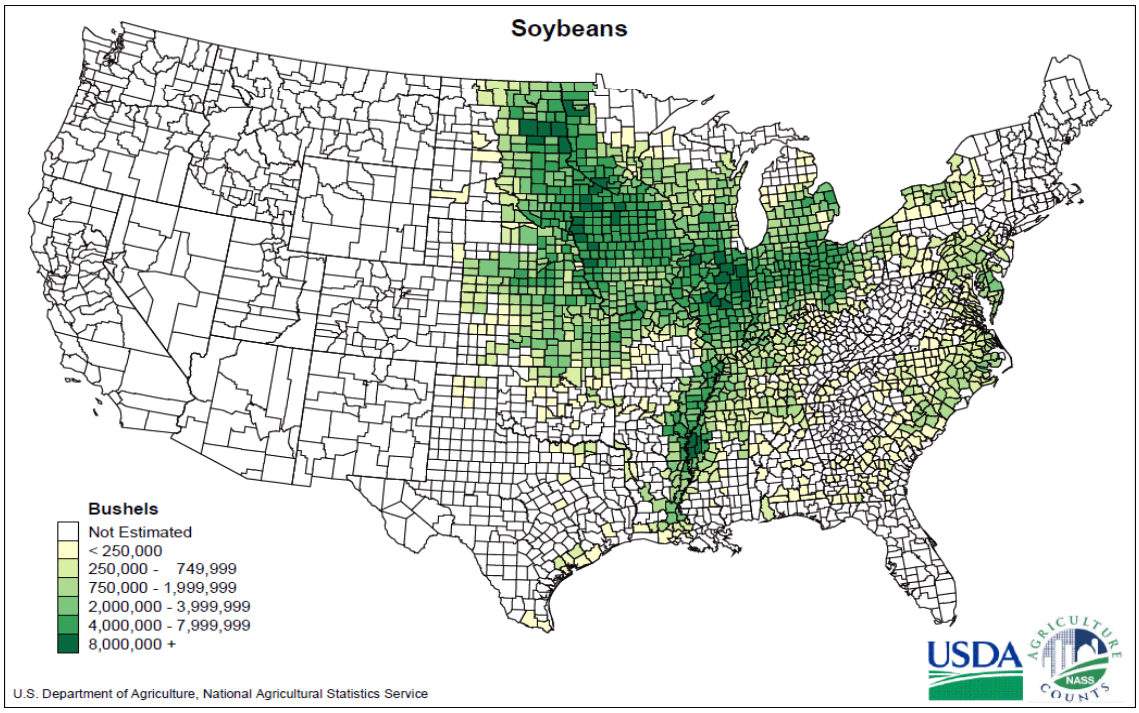
Source:
U.S. Department of Agriculture, 2009. *Summary Report: 2007 National Resources Inventory* , Natural Resources Conservation Service, Washington, DC, and Center for Survey Statistics and Methodology, Iowa State University, Ames, Iowa. 123 pages.
http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1041379.pdf

Note:
Cropland includes CRP Land, which is reported separately in the source document.
CRP = Conservation Reserve Program

Location of commodity crop production shows where agricultural residues are potentially available for collection and energy crops potentially available for production.

Section: INTRODUCTION
Geographic Locations of Major Crops, 2010
(production acreage by county)





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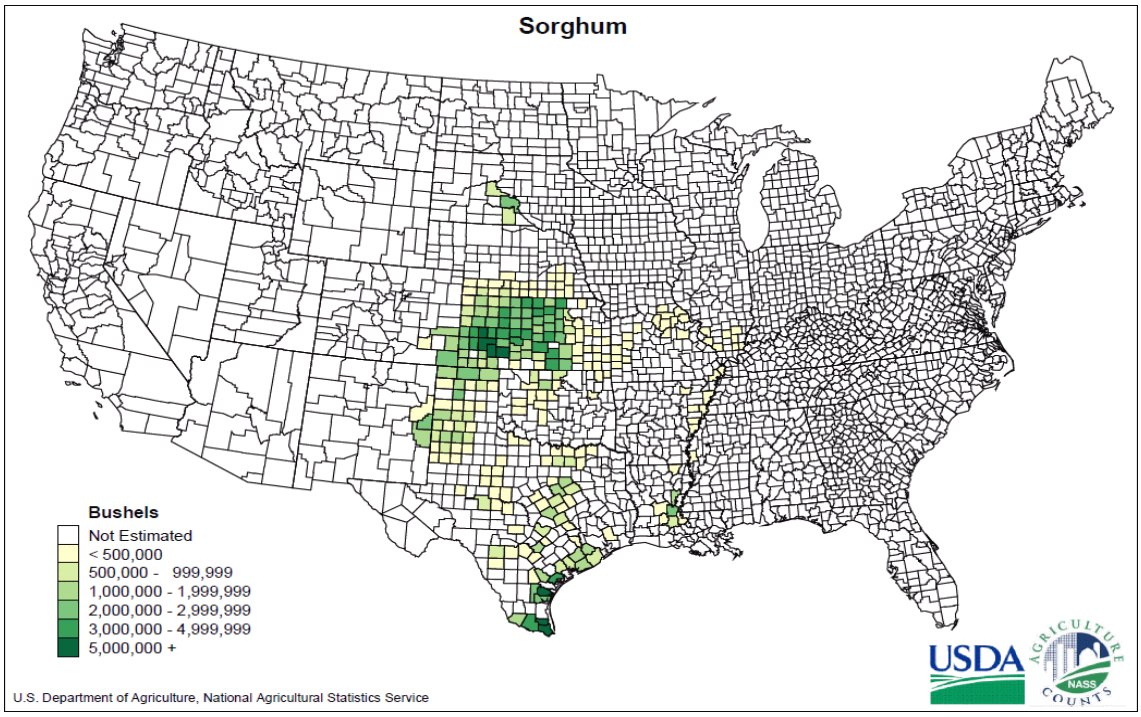

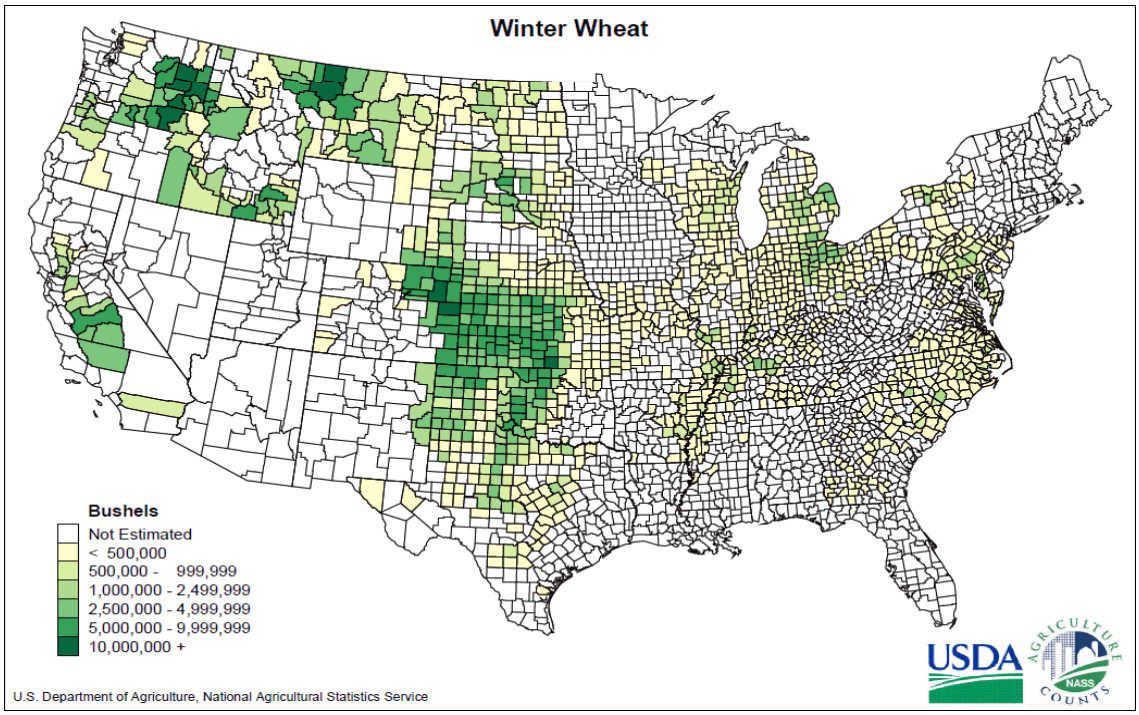

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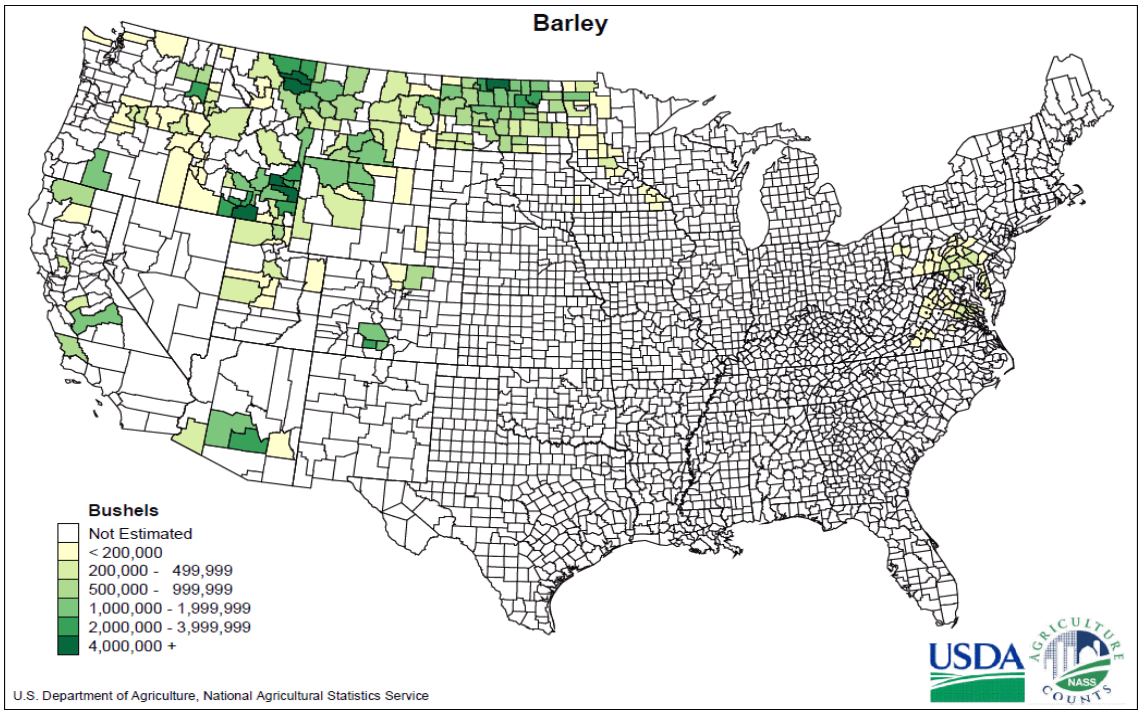

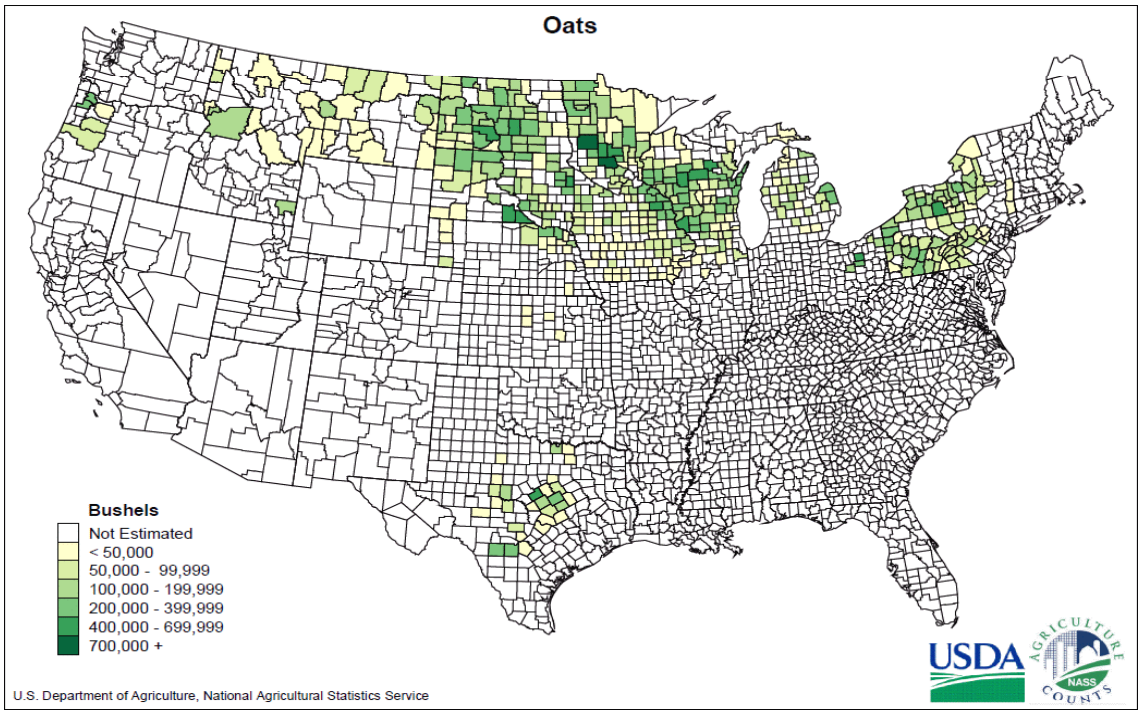

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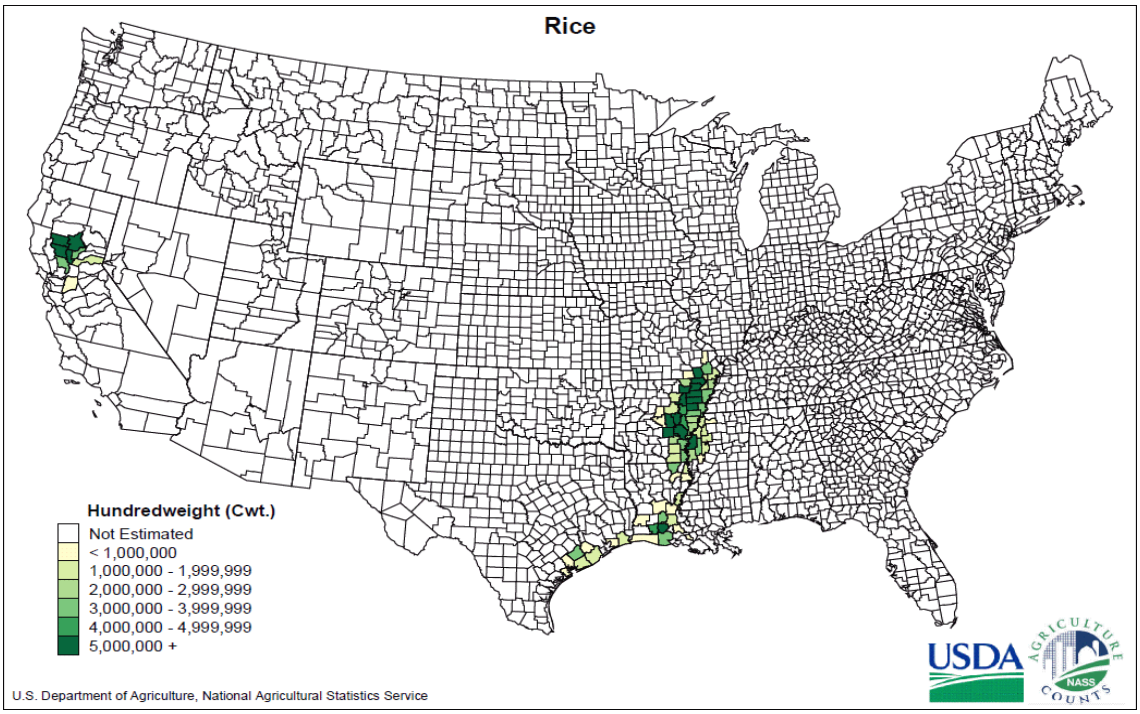
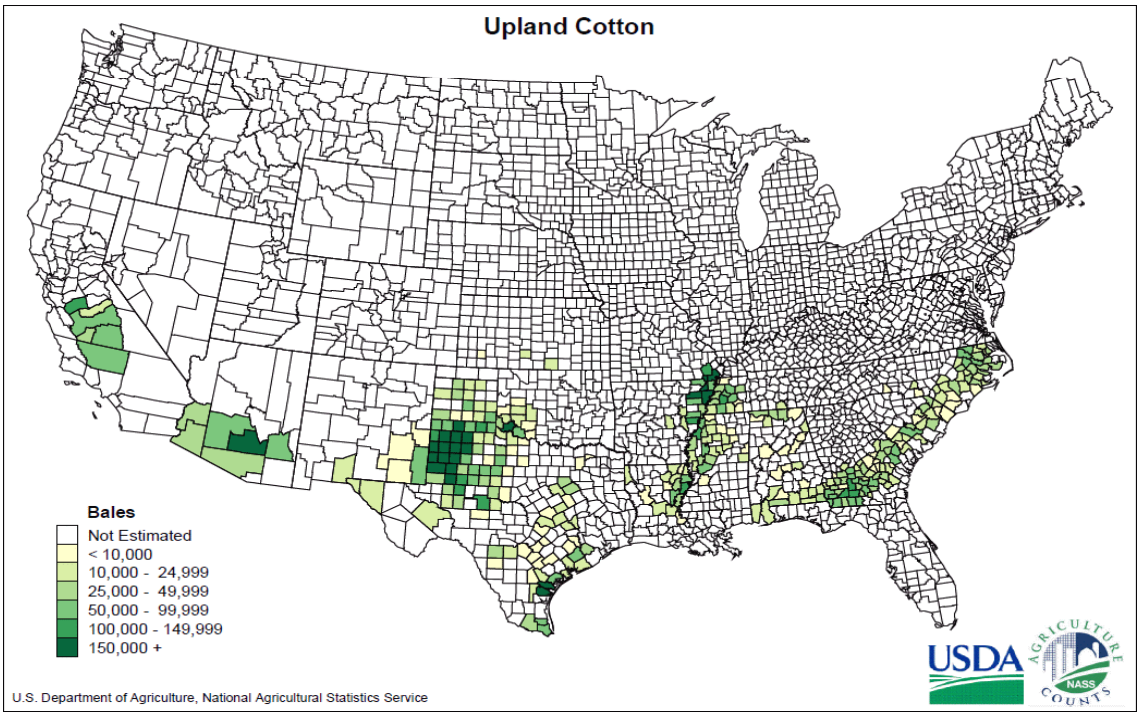


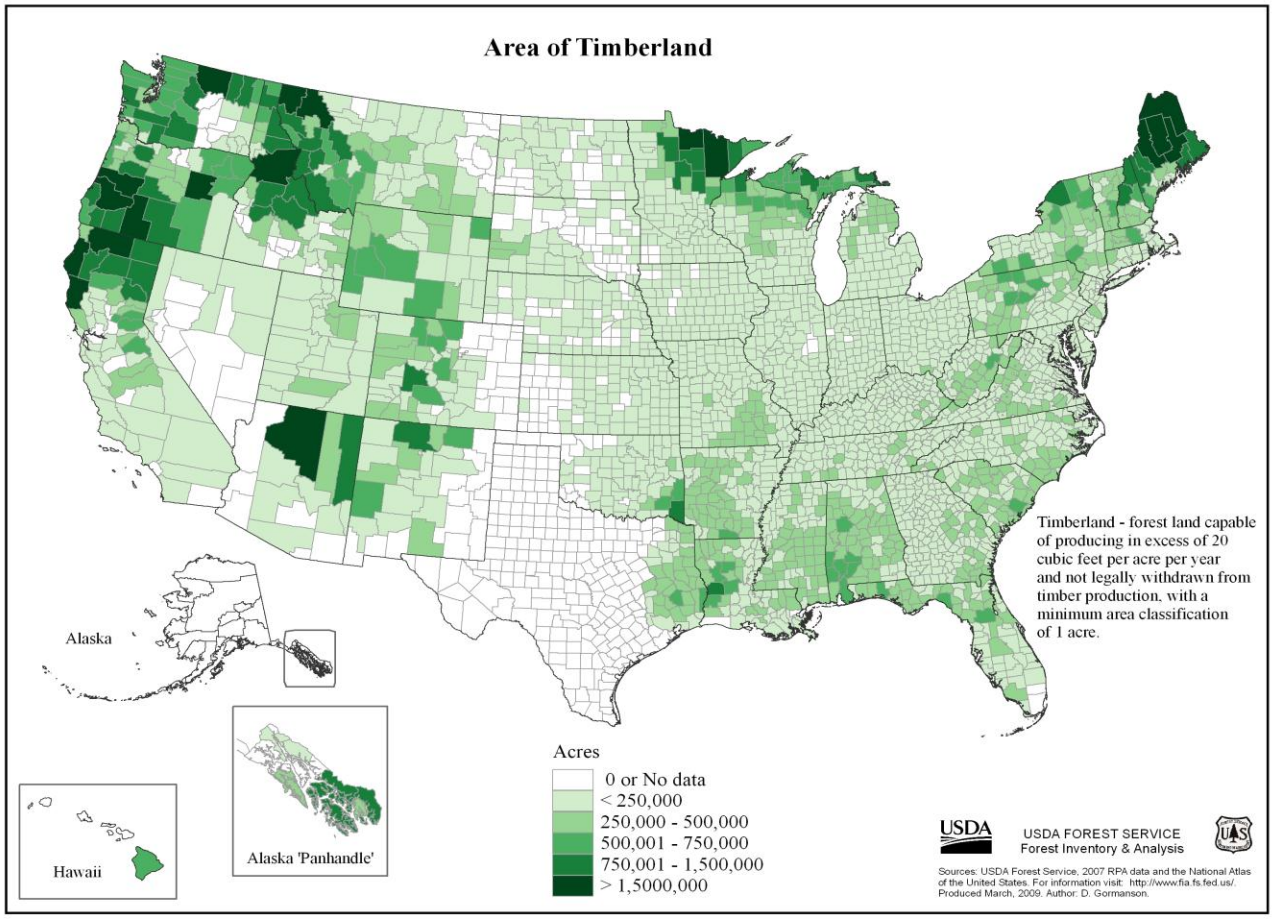


Source:
U.S. Department of Agriculture, National Agricultural Statistics Service
http://www.nass.usda.gov/Charts_and_Maps/A_to_Z/index.asp#h

This map shows the spatial distribution of the nation's timberland in 2007 by county. Nationwide, there are 514 million acres of forest land classified as timberland. This land is the source of a wide variety of forest products and forest residue feedstocks, such as logging residue and fuel treatment thinnings to reduce the risk of fire.

In this map, timberland is defined as forest land capable of producing in excess of 20 cubic feet per acre per year and not legally withdrawn from timber production, with a minimum area classification of 1 acre.

Section: INTRODUCTION
Geographic Distribution of Timberland by County, 2007



Source:
USDA Forest Service, 2007 RPA data, available at:
http://fia.fs.fed.us/tools-data/maps/2007/descr/ytim_land.asp
USDA Forest Service, Forest Inventory and Analysis. 2007 RPA data and the National Atlas of the United States.

Currently used biomass feedstocks are largely derived from agriculture and the forestry sector, with the majority of that being used by the forestry sector to generate energy for industrial processes. Fuelwood, another substantial category includes the residential and commercial sector as well as biomass consumed by the electric utility industry in dedicated biomass plants and co-firing applications. Municipal solid waste (MSW) sources are allocated to forestry (65%) and cropland (35%) sectors. Ethanol and biodiesel projections are based on federal mandates of 15 billion gallons per year of biofuels and 1 billion gallons per year of biodiesel. The ethanol numbers assume corn grain at 56 pounds per bushel, 15.5% moisture content, and 2.8 gallons per bushel.

Section: INTRODUCTION
Projected Consumption of Currently Used Biomass Feedstocks by Source
(Million Dry Tons per Year)

Source	Current	2017	2022	2030
Forest				
Fuelwood	38	72	96	106
Mill Residue	32	38	39	42
Pulping liquors	45	52	54	58
MSW sources	14	20	20	20
Total Forest	**129**	**182**	**210**	**226**
Agriculture				
Ethanol[a]	76(109)	88(127)	88(127)	88(127)
Biodiesel[b]	2	4	4	4
MSW sources	7	11	11	11
Total agricultural	**85(118)**	**103(142)**	**103(142)**	**103(143)**
Total Currently Used Resources	**214 (247)**	**284(342)**	**312(351)**	**328(368)**

Sources:

Perlack, R. D., and B. J. Stokes. *U.S. Billion-Ton Update: Biomass Supply for a Bioenergy and Bioproducts Industry*, ORNL/TM-2010/224, Oak Ridge National Laboratory, Oak Ridge, TN, 2011.

Bioenergy Knowledge Discovery Website, https://bioenergykdf.net

[a] The first number is the portion of corn consumed to make ethanol. The number in parenthesis is the amount of corn required. For example, it takes 127.5 million dry tons to make 15 billion gallon per year of ethanol. However, only 88.3 million dry tons are consumed in making the ethanol. The remainder (39.2 million dry tons) is distiller's grain and is excluded from the total.

[b] Included all sources of biodiesel. Current consumption is 43% from soybeans and 57% from other sources, including animal fats and waste oils. The proportion of sources of future feedstocks will vary and are assumed to have an average conversion rate of 7.5 pounds of oil/fats per gallon of diesel.

In 2022 the revised Renewable Fuels Standard (RFS) mandates the use of 36 billion gallons per year (BGY) of renewable fuels (with 20 billion gallons coming from cellulosic biofuels). The feedstock shown in the baseline scenario accounts for conventional biofuels (corn grain, ethanol, and biodiesel) and shows 602 million dry tons of potential lignocellulosic biomass resource. This potential resource is more than sufficient to provide feedstock to produce the required 20 billion gallons of cellulosic biofuels. The high-yield scenario demonstrates a potential that far exceeds the RFS mandate.

Section: INTRODUCTION
Summary of Currently Used and Potential Biomass
(Million Dry Tons)

Feedstock	2012	2017	2022	2030
		Baseline scenario		
Forest resources currently used	129	182	210	226
Forest biomass & waste resource potential	97	98	100	102
Agricultural resources currently used	85	103	103	103
Agricultural biomass & waste resource potential	162	192	221	265
Energy crops[1]	0	101	282	400
Total currently used	**214**	**284**	**312**	**328**
Total potential resources	**258**	**392**	**602**	**767**
Total baseline	**473**	**676**	**914**	**1094**
		High-yield scenario (2%-4%)		
Forest resources currently used	129	182	210	226
Forest biomass & waste resource potential	97	98	100	102
Agricultural resources currently used	85	103	103	103
Agricultural biomass & waste resource potential[2]	244	310	346	404
Energy crops	0	139-180	410-564	540-799
Total currently used	**214**	**284**	**312**	**328**
Total potential	**340**	**547-588**	**855-1009**	**1046-1305**
Total high-yield (2-4%)	**555**	**831-872**	**1168-1322**	**1374-1633**

Sources:

Perlack R. D., L. L. Wright, A. F. Turhollow, R. L. Graham, B. J. Stokes, and D. C. Erbach, *Biomass as Feedstock Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-ton Annual Supply,* ORNL/TM-2005/66. Oak Ridge National Laboratory, Oak Ridge, TN, 2005. http://www1.eere.energy.gov/biomass/publications.html

Perlack, R. D., and B. J. Stokes (Leads), *U.S. Billion-Ton Update: Biomass Supply for a Bioenergy and Bioproducts Industry* , ORNL/TM-2011/224. Oak Ridge National Laboratory, Oak Ridge, TN, 2011.

Note: Under the high-yield scenario, energy crops are shown for 2% to 4% annual increase in yield. Numbers may not add due to rounding.

The summary assumes price paid is $60 per dry ton or less at the farm gate or forest edge and thus does not include additional costs to preprocess, handle or transport the feedstock. Scenario descriptions are discussed in the Biomass Resource Overview text and in the 2011 reference below.