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Fuel Sources and Carbon Dioxide Emissions by Electric Power Plants in the United States[1]

Alan W. Hodges and Mohammad Rahmani[2]

Introduction

The issue of global warming has drawn more attention in recent years due to rising sea levels, glacier retreat, Arctic shrinking, and altered patterns of agriculture (National Geographic 2007). Human activities add to global warming through carbon dioxide released by using coal, petroleum, natural gas, and other sources to produce energy for human consumption (IPCC 2007). Global warming has become an issue of concern because of its negative effects on the environment, human health, and economic well-being of all the people of the world (U.S. EPA 2008). The Intergovernmental Panel on Climate Change (IPCC) has set the goal of reducing carbon dioxide to 350 ppm (parts per million) by 2025 (EEA 2008). Nations and the international community as a whole are trying to bring the rate of increase in emissions of greenhouse gases under control, or to mitigate the effects of such emissions through carbon capture and storage (sequestration) technologies. Renewable Portfolio Standard (RPS) and Renewable Fuel Standard (RFS) policies adopted by many states are efforts to mitigate carbon dioxide emissions (USDOE/EIA 2008). RPS requires electric power facilities to use a minimum percentage of their fuel from renewable sources, and RFS requires blending of renewable fuels (ethanol) with gasoline at specified minimum levels.

Carbon dioxide (CO_2) accounted for nearly 85 percent of total greenhouse gas emissions in 2006, with the balance from methane (CH_4), nitrogen oxides (NO_2), and fluorocarbons (HFC, PFC, and SF_6). Electric power generation contributed almost 41 percent of the CO_2 emissions from fossil fuels in the United States and 34 percent of all greenhouse gas emissions, the largest share of all major sectors of the U.S. economy, as shown in Table 1 (U.S. EPA 2008). Most electric power plants utilize coal and natural gas as the principal fuels. However, some are beginning to use non-polluting energy sources (e.g., sun, wind, and hydropower) and biomass fuels (which have little or no net emissions over the life cycle of feedstock growth and bio-fuel use) to generate electricity.

This report summarizes trends in carbon dioxide emissions of electric power plants by type of fuel and by state in the United States during the 2003–2007 period.

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2. Alan W. Hodges, extension scientist, and Mohammad Rahmani, coordinator of economic analysis, Food and Resource Economics Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida, Gainesville, FL.

Data

This analysis uses monthly data, summarized annually for 2003–2007, on fuel consumption and electricity generation by electric power plants and industrial heat and power systems in the United States. The data are collected and published by the U.S. Department of Energy, Energy Information Administration (USDOE/EIA). Carbon dioxide uncontrolled emission factors are used to estimate the annual volume of carbon dioxide emissions by type of fuel used for electricity generation. Emission factors are the amount of carbon dioxide emitted per unit energy generated (pounds per million Btu/MMBtu) for each fuel type, based on EIA and Environmental Protection Agency (U.S. EPA) estimates. The most recent emission factors available from the 2000–2007 U.S. EPA studies were used for this analysis. The emission factor for mixed biogenic and non-biogenic municipal solid waste was adjusted upward based on U.S. EPA estimates from a 1997 study which showed that municipal solid waste in the United States contained 15.9 percent plastics. Table 2 shows the carbon dioxide emission factors by fuel groups and specific energy sources. Of course, nuclear and most renewable energy sources do not have direct CO_2 emissions. While biomass fuels do emit CO_2 upon combustion, the carbon is reabsorbed by growing plants over the lifecycle of biofuel production. However, direct emissions from biomass combustion are included in this analysis.

Electricity Generation and Fuel Types

The total electricity generation by electric power plants in the United States, net of internal uses, was about 4.2 gigawatt-hours (GWh, billion watt-hours) in 2007, as shown in Table 3. Three major fuel groups were used by electric power plants to generate electricity: coal, at over 48 percent, or more than 2 billion watt-hours; natural gas and propane, at over 21 percent, or nearly 900 million watt-hours; and nuclear energy, at 19 percent, or more than 800 million watt-hours. Renewable sources of energy, such as solar, geothermal, water, and wind, generated a total of 291 million watt-hours, or 7 percent of total electricity, and biomass generated 64 million watt-hours, or 1.5 percent, to the net electricity generation in the United States in 2007 (Table 3).

Trends in electricity generation for each energy source during the 2003–2007 period are summarized in Table 3, and charted for major fuel groups in Figure 1. Total electricity generation increased by about 7 percent between 2003 and 2007. Generation from natural gas and propane showed a significant increase of more than 37 percent during this time. Generation from all non-biomass renewable energy sources, such as solar, water, wind, and geothermal, which result in no or minimal emissions of carbon dioxide, actually decreased during this period. However, use of solar energy to produce electricity increased by more than 13 percent during the 2003–2007 period. Wind is now the fastest growing source of electricity due to substantial investments, particularly in the Great Plains region of the United States, with generation increasing by almost threefold over the last five years. Major efforts to promote greater use of biomass fuels for electricity generation have resulted in this source increasing by over 7 percent. It should be noted that biomass is considered carbon neutral because the carbon released during combustion is recaptured through plant growth. Woody biomass captures carbon from the atmosphere, whereas fossil fuels transfer underground carbon to the atmosphere (Biomass Energy Resource Center 2008). Higher petroleum prices have negatively affected the use of this fuel for generating electricity, decreasing its share by 51 percent since 2003, and it now represents only a little more than 1 percent of all fuel types used for electricity in 2007.

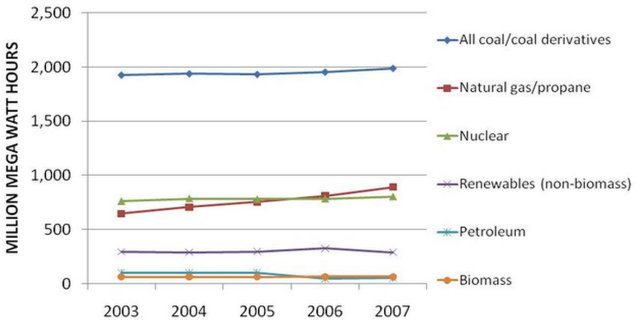

Figure 1. Net electricity generation by U.S. power plants by major fuel groups, 2003–2007.

Carbon Dioxide Emissions and Fuel Types

The total carbon dioxide emissions by electric power plants in the United States exceeded 2.5 billion metric tons (2.756 Bn tons) in 2007 (Table 4). The largest fuel groups—coal, natural gas, and propane—dominated carbon dioxide emissions, over 94 percent of the total in 2007. Coal alone represented 78 percent of all CO_2 emissions by electric power plants, or nearly 2 billion metric tons in 2007.

While total carbon dioxide emissions by power plants increased by 5 percent between 2003 and 2007, various fuel types showed different trends during this period. Bituminous coal, the highest contributor to power plant CO_2 emissions in 2007 (38%), showed a slight decrease of 1.6 percent when compared to 2003, whereas sub-bituminous coal, the second largest contributor to CO_2 emissions, registered an almost 9 percent increase between 2003 and 2007. Lignite coal, with only a 3.5 percent share of CO_2 emissions in 2007, decreased its contribution towards CO_2 emissions by more than 10 percent. At the same time, the share of emissions from coal-based synfuels increased by more than 26 percent. Natural gas showed an increase in CO_2 emissions of more than 34 percent between 2003 and 2007. Biomass accounted for only 2.7 percent of CO_2 emissions in 2007, but its share of carbon dioxide emissions decreased by 6 percent between 2003 and 2007. Figure 2 illustrates the trend during the 2003–2007 period in CO_2 emissions for the major fuel groups.

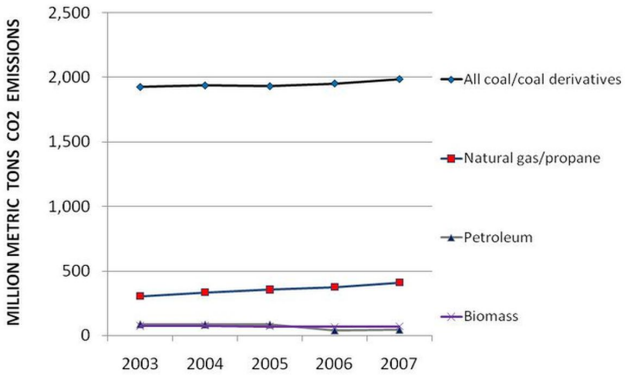

Figure 2. CO_2 emissions by U.S. power plants by major fuel groups, 2003–2007.

Emission Ratios

The emission ratio represents the amount of CO_2 emitted per unit of electricity generated (metric tons CO_2 per megawatt-hour). This relationship was used to compare CO_2 emissions by electric power plants across the United States, irrespective of differences in area, population, and other characteristics. Emission ratios are shown in Table 5 by state for 2007 and 2003 and the percentage change during this period. Power plants in states with lower emission ratios used more environmentally friendly fuel sources than those with higher emission ratios. Vermont and Washington had the lowest emission ratios of 0.09 and 0.13, respectively, in 2007, and the highest decrease in emission ratios during the 2003–2007 period. Wyoming and North Dakota had the highest emission ratios of 0.99 and 1.02, respectively (Table 5).

Conclusions

Coal contributed over 78 percent of the total carbon dioxide emissions by electric power plants, but generated less than half (48.6%) of all the electricity generated by U.S. power plants in 2007. Natural gas showed significantly lower CO_2 emissions for the electricity it generated (16% of CO_2 emissions for 21.5% of the generated electricity). Biomass fuels produced only 0.5 percent of the electricity in 2007and caused 2.7 percent of the CO_2 emissions. Non-biomass renewable fuel sources generated 7 percent of the electricity and produced less than 0.1 percent of carbon dioxide emissions. Nuclear energy generated a significant share of electricity (19.4%). However, the claim that nuclear energy does not cause any CO_2 emissions has been challenged by the fact that extraction, production, and processing of fissile fuels (uranium, plutonium, and thorium) indirectly involve greenhouse gas emitting industries (Fritsche 1997). While the trend for electricity generation between 2003 and 2007 showed a 37 percent increase in natural gas usage, the use of non-polluting energy sources (e.g., sun, wind, and hydropower) registered a 1.1 percent decrease during the same time period. A 183 percent increase in wind energy usage during the 2003–2007 period is evidence of the potential for wind energy, although its share in electricity generation is still very small (0.8 percent).

A recent report by the International Energy Agency estimated that $45 trillion is needed to cut world carbon emissions in half by 2050 (Kanter 2008). Certainly, a major portion of this amount will be spent on low- or non-CO_2 emitting sources of energy. The application of new technologies for using solar energy and an increased focus on wind energy for electricity generation show great promise in reducing CO_2 emissions. States such as Nebraska, Nevada, New York, Oklahoma, Vermont, and Washington have reduced their emission ratios by over 10 percent since 2003 using energy sources with lower CO_2 emissions.

To reduce greenhouse gas emissions, many states have adopted a Renewable Portfolio Standard policy requiring electric power facilities to reach a specified minimum percentage of their fuels from renewable resources by a certain date (USDOE/EIA 2007). Presently, 30 states (including the District of Columba) have adopted a mandatory Renewable Portfolio Standard (RPS), and four states have voluntary goals. The mandated goals for renewable resource use range from 4 percent in Massachusetts in 2009 to 25 percent in Illinois, Minnesota, and Oregon in 2025 (USDOE/EIA 2007). It is assumed that the use of renewable energy resources will reduce greenhouse gas emissions. Renewable Portfolio Standards may bring economic and health benefits such as job creation and cleaner air in addition to reducing greenhouse gas emissions (PEW Center 2008).

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Table 1. Greenhouse gas emissions by major sectors of the U.S. economy, 2006.

Sector	Emissions	Percent of Total
	(*Tg CO_2 equivalent*)	(%)
Electric Power	2,338	34
Transportation	1,970	28
Industry	1,372	20
Agriculture	534	8
Commercial	395	6
Residential	345	5
Total	6,952	100

Source: U.S. Environmental Protection Agency (2008).

Table 2. Carbon dioxide emission factors for electric power generation by fuel types in the United States.

Fuel Group	Energy Source	Pounds Per Million Btu
Biomass	Agriculture Crop Byproducts	195.0
	Black Liquor	195.0
	Landfill Gas	115.1
	Municipal Solid Waste (mixed biogenic & non-biogenic)	179.6
	Municipal Solid Waste (non-biogenic)	195.0
	Other Biomass Gases	115.1
	Other Biomass Liquid (ethanol, fish oil)	115.1
	Other Biomass Solid (animal manure; waste)	195.0
	Sludge Waste	199.5
	Wood Waste Liquids (red liquor; sludge wood)	195.0
	Wood Waste Solids (paper; pellets; railroad ties; utility poles)	195.0
Coal	Bituminous and Anthracite Coal	205.3
	Lignite Coal	215.4
	Coal-Based Synfuel (briquettes; pellets; extrusions)	205.3
	Sub-Bituminous Coal	212.7
	Waste / Other Coal	205.3

Table 2. Carbon dioxide emission factors for electric power generation by fuel types in the United States.

Fuel Group	Energy Source	Pounds Per Million Btu
Natural Gas & Propane	Natural Gas	117.1
	Propane	139.2
Nuclear	Nuclear (uranium; plutonium; thorium)	0.0
Petroleum	Distillate Fuel Oil (diesel and No. 1, 2 & 4 fuel oils)	161.4
	Jet Fuel	156.3
	Kerosene	159.5
	Residual Fuel Oil (No. 5, 6 & Bunker C fuel oil)	173.9
	Waste Oil (liquid butane; crude oil; liquid byproducts	210.0
Renewables (non-biomass)	Solar (photvoltaic; thermal)	0.0
	Geothermal	16.6
	Water (conventional; pumped storage)	0.0
	Wind	0.0
Residual	Blast Furnace Gas	117.0
	Municipal Solid Waste (non-biogenic)	91.9
	Other Gas (butane; coal processes; coke-oven)	141.5
	Other (batteries; chemicals; coke breeze; hydrogen)	0.0
	Petroleum Coke	225.1
	Purchased Steam	0.0
	Tires	189.5

Source: Energy Information Administration, Carbon Dioxide Uncontrolled Emission Factors, Electric Power Annual Data for 2000–2007 (http://www.eia.doe.gov/cneaf/electricity/epa/epata3.html).

Table 3. Net electricity generation by energy source in the United States, 2003–2007.

Fuel Group and Energy Source	2003	2004	2005	2006	2007	Change 2003–07	Share 2007
	(*gigawatt–hours*)					(%)	(%)
Coal	1,973,737	1,978,620	2,013,179	1,990,926	2,020,572	2.4	48.6
Bituminous and Anthracite Coal	1,063,588	1,022,139	1,042,601	1,039,727	1,040,008	–2.2	25.0
Lignite Coal	91,834	88,973	91,054	88,382	82,894	–9.7	2.0
Coal-Based Synfuel	55,508	71,339	70,241	57,287	73,135	31.8	1.8
Sub-Bituminous Coal	753,820	785,637	796,645	791,639	810,150	7.5	19.5
Waste / Other Coal	8,987	10,531	12,639	13,890	14,385	60.1	0.3
Natural Gas & Propane	649,924	708,875	757,989	813,061	893,244	37.4	21.5
Natural Gas	649,908	708,853	757,974	813,044	893,211	37.4	21.5
Propane	16	21	15	17	32	101.4	0.0
Nuclear (uranium; plutonium; thorium)	763,733	788,528	781,986	787,219	806,487	5.6	19.4
Renewable (non-biomass)	294,514	290,275	297,441	326,492	291,171	–1.1	7.0
Solar	534	575	550	508	606	13.5	0.0
Geothermal	14,424	14,811	14,692	14,568	14,839	2.9	0.4
Water	267,271	259,929	263,763	282,689	241,319	–9.7	5.8
Wind	11,187	14,144	17,811	26,589	32,143	187.3	0.8
Biomass	62,140	61,749	62,714	63,425	64,073	3.1	1.5
Agricultue Crop Byproducts	725	747	675	661	726	0.2	0.0
Black Liquor	18,660	17,782	18,230	18,268	18,231	–2.3	0.4
Landfill Gas	5,077	5,128	5,135	5,677	6,200	22.1	0.1
Municipal Solid Waste	15,102	14,824	14,883	15,137	15,234	0.9	0.4
Other Biomass Gases	1,088	840	758	788	854	–21.4	0.0
Other Biomass Liquid	8	12	7	10	11	44.4	0.0
Other Biomass Solid	345	408	369	315	296	–14.3	0.0

Table 3. Net electricity generation by energy source in the United States, 2003–2007.

Fuel Group and Energy Source	2003	2004	2005	2006	2007	Change 2003–07	Share 2007
	(*gigawatt–hours*)					(%)	(%)
Sludge Waste	263	209	200	181	229	–12.9	0.0
Wood Waste Liquids	647	315	197	154	72	–88.8	0.0
Wood Waste Solids	18,222	19,479	20,254	20,227	20,212	10.9	0.5
Petroleum	102,734	100,040	100,095	44,655	49,956	–51.4	1.2
Distillate Fuel Oil	15,169	10,660	11,198	7,236	8,423	–44.5	0.2
Jet Fuel	60	277	338	302	597	902.3	0.0
Kerosene	439	422	517	185	482	9.8	0.0
Residual Fuel Oil	85,940	87,551	87,189	36,054	39,561	–54.0	1.0
Waste Oil	1,127	1,129	853	877	893	–20.7	0.0
Residual	39,504	45,289	44,648	49,731	44,948	13.8	1.8
Blast Furnace Gas	2,826	3,513	3,689	3,574	3,383	19.7	0.1
Municipal Solid Waste (non-biogenic)	*	*	*	6,661	6,666	**	0.2
Other Gas	12,758	13,232	12,613	12,469	11,999	–6.0	0.3
Other	5,024	5,863	4,124	3,925	3,697	–26.4	0.1
Petroleum Coke	16,672	20,731	22,427	19,709	15,752	–5.5	0.4
Purchased Steam	1,097	816	625	2,139	2,264	106.3	0.1
Tires	1,128	1,134	1,171	1,254	1,188	5.3	0.0
Total All Fuel Types	3,883,185	3,970,555	4,055,423	4,064,702	4,159,514	7.1	100.0
Year-Over-Year Percent Change		2.25	2.14	0.23	2.33		

* Reported as mixed municipal solid waste.
** Added to municipal solid waste-biogenic (MSB) for percentage calculation.

Table 4. Carbon dioxide emissions by U.S. electric power plants by energy source, 2003–2007.

Fuel Group and Energy Source	2003	2004	2005	2006	2007	Change 2003–07	Share 2007
	(*1,000 metric tons*)					(%)	(%)
Coal	1,927,847	1,939,598	1,933,992	1,954,332	1,987,563	3.1	78.1
Bituminous and Anthracite Coal	1,002,095	968,583	986,591	982,394	985,365	–1.7	38.7
Lignite Coal	100,958	94,349	52,427	95,244	90,281	–10.6	3.5
Coal-Based Synfuel	52,449	66,406	64,158	52,197	66,462	26.7	2.6
Sub-Bituminous Coal	761,676	797,903	816,458	808,874	829,454	8.9	32.6
Waste / Other Coal	10,669	12,358	14,359	15,623	16,001	50.0	0.6
Natural Gas & Propane	304,670	333,614	354,359	375,018	409,854	34.5	16.1
Natural Gas	304,659	333,597	354,348	375,007	409,828	34.5	16.1
Propane	11	17	11	11	26	134.6	0.0
Biomass	73,967	75,700	70,677	66,292	69,462	–6.1	2.7
Agricultue Crop Byproducts	1,253	1,115	1,109	1,122	1,270	1.4	0.0
Black Liquor	21,335	23,069	18,448	19,744	21,509	0.8	0.8
Landfill Gas	3,439	3,644	3,483	4,001	4,426	28.7	0.2
Municipal Solid Waste	21,932	22,207	22,052	13,679	13,935	–13.2	0.7
Other Biomass Gases	597	487	511	519	539	–9.7	0.0
Other Biomass Liquid	6	6	3	5	5	–17.8	0.0
Other Biomass Solid	479	671	528	507	510	6.4	0.0
Sludge Waste	329	381	270	214	267	–19.0	0.0
Wood Waste Liquids	789	201	150	339	103	–87.0	0.0
Wood Waste Solids	23,808	23,920	24,024	26,161	26,897	13.0	1.1

Table 4. Carbon dioxide emissions by U.S. electric power plants by energy source, 2003–2007.

Fuel Group and Energy Source	2003	2004	2005	2006	2007	Change 2003–07	Share 2007
	(*1,000 metric tons*)					(%)	(%)
Petroleum	85,062	82,894	82,691	37,405	42,067	–50.5	1.7
Distillate Fuel Oil	12,604	8,789	9,000	5,685	7,049	–44.1	0.3
Jet Fuel	58	200	254	213	377	553.2	0.0
Kerosene	354	374	421	168	412	16.5	0.0
Residual Fuel Oil	71,178	72,493	72,275	30,554	33,474	–53.0	1.3
Waste Oil	868	1,038	742	784	755	–13.0	0.0
Residual	28,770	35,573	36,524	39,747	34,607	20.3	1.4
Blast Furnace Gas	2,188	2,281	2,702	2,885	2,472	13.0	0.1
Municipal Solid Waste (non-biogenic)	*	*	*	5,065	5,105	**	0.2
Other Gas	7,400	9,215	8,077	8,124	7,662	3.5	0.3
Petroleum Coke	18,040	22,835	24,447	22,203	17,936	–0.6	0.7
Tires	1,142	1,242	1,298	1,470	1,431	25.3	0.1
Non-Biomass Renewables / Geothermal	2,283	2,344	2,325	2,305	2,348	2.9	0.1
Total All Sources	2,422,599	2,469,723	2,480,568	2,475,098	2,545,900	5.1	100.0
Annual Percent Change		1.95	0.44	–0.22	2.86		

* Reported as mixed municipal solid waste.
** Added to municipal solid waste-biogenic (MSB) for percentage calculation.

Table 5. Emission ratios by U.S. power plants, 2003 and 2007, and percent change.

State	Electricity Generation, 2007	Carbon Dioxide Emissions, 2007	Emission Ratio, 2003	Emission Ratio, 2007	Change Emission Ratio 2003–07
	(*gigawatt–hours*)	(*1,000 metric tons*)	(*metric tons per megawatt–hour*)	(*metric tons per megawatt–hour*)	(*%*)
Vermont	6,382	576	0.14	0.09	–37
Nevada	31,888	16,615	0.70	0.52	–26
Washington	106,079	14,078	0.16	0.13	–18
Oklahoma	72,253	51,036	0.80	0.71	–12
New York	146,499	53,821	0.41	0.37	–10
Nebraska	32,957	20,866	0.71	0.63	–10
Iowa	49,760	41,351	0.91	0.83	–9
New Hampshire	23,413	8,425	0.39	0.36	–8
Virginia	78,594	42,239	0.58	0.54	–8
Florida	225,832	132,280	0.63	0.59	–7
New Mexico	35,953	31,800	0.96	0.88	–7
Connecticut	33,494	10,953	0.35	0.33	–6
New Jersey	63,088	20,888	0.35	0.33	–6
Kansas	50,080	39,179	0.83	0.78	–6
Colorado	52,954	42,872	0.86	0.81	–6
Massachusetts	47,513	26,601	0.59	0.56	–5
Minnesota	53,611	36,949	0.73	0.69	–5
Mississippi	49,880	29,216	0.61	0.59	–4
Wisconsin	63,402	47,227	0.78	0.74	–4
Ohio	156,069	130,774	0.87	0.84	–4
Utah	43,691	38,355	0.91	0.88	–4
Missouri	91,147	77,281	0.87	0.85	–3
Wyoming	45,581	45,180	1.03	0.99	–3
Rhode Island	7,049	2,997	0.43	0.42	–2
Arkansas	55,074	30,839	0.57	0.56	–2
Pennsylvania	227,278	131,161	0.59	0.58	–2
Texas	405,582	258,103	0.65	0.64	–1
Maryland	49,968	31,159	0.63	0.62	–1
Montana	28,491	20,199	0.71	0.71	0
Arizona	113,022	55,854	0.49	0.49	0

Table 5. Emission ratios by U.S. power plants, 2003 and 2007, and percent change.

State	Electricity Generation, 2007	Carbon Dioxide Emissions, 2007	Emission Ratio, 2003	Emission Ratio, 2007	Change Emission Ratio 2003–07
	(*gigawatt–hours*)	(*1,000 metric tons*)	(*metric tons per megawatt–hour*)	(*metric tons per megawatt–hour*)	(*%*)
Maine	15,660	8,348	0.53	0.53	0
Louisiana	92,766	54,669	0.59	0.59	0
Michigan	120,282	80,972	0.67	0.67	0
West Virginia	93,940	84,886	0.90	0.90	0
Indiana	130,728	124,119	0.94	0.95	1
North Dakota	30,820	31,573	1.02	1.02	1
Idaho	11,319	2,044	0.18	0.18	2
Kentucky	97,477	93,899	0.94	0.96	2
Illinois	200,332	101,608	0.49	0.51	3
Alabama	144,575	91,482	0.61	0.63	4
Hawaii	11,714	9,703	0.80	0.83	4
Georgia	145,394	97,958	0.64	0.67	5
Delaware	8,510	7,836	0.88	0.92	5
South Carolina	103,911	44,712	0.41	0.43	6
Tennessee	94,930	57,854	0.58	0.61	6
California	214,099	67,108	0.29	0.31	8
North Carolina	130,239	79,783	0.57	0.61	8
Oregon	53,578	11,197	0.`9	0.21	9
Alaska	6,888	4,128	0.55	0.60	9
South Dakota	5,664	3,061	0.46	0.54	16