U.S. Renewable Energy Technical Potentials: A GIS-Based Analysis

Anthony Lopez, Billy Roberts, Donna Heimiller, Nate Blair, and Gian Porro

NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency & Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

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Executive Summary

The National Renewable Energy Laboratory (NREL) routinely estimates the technical potential of specific renewable electricity generation technologies. These are technology-specific estimates of energy generation potential based on renewable resource availability and quality, technical system performance, topographic limitations, environmental, and land-use constraints only. The estimates do not consider (in most cases) economic or market constraints, and therefore do not represent a level of renewable generation that might actually be deployed.

This report is unique in unifying assumptions and application of methods employed to generate comparable estimates across technologies, where possible, to allow cross-technology comparison. Technical potential estimates for six different renewable energy technologies were calculated by NREL, and methods and results for several other renewable technologies from previously published reports are also presented. Table ES-1 summarizes the U.S. technical potential, in generation and capacity terms, of the technologies examined.

The report first describes the methodology and assumptions for estimating the technical potential of each technology, and then briefly describes the resulting estimates. The results discussion includes state-level maps and tables containing available land area (square kilometers), installed capacity (gigawatts), and electric generation (gigawatt-hours) for each technology.

Table ES-1. Total Estimated U.S. Technical Potential Generation and Capacity by Technology

Technology	Generation Potential (TWh)[a]	Capacity Potential (GW)[a]
Urban utility-scale PV	2,200	1,200
Rural utility-scale PV	280,600	153,000
Rooftop PV	800	664
Concentrating solar power	116,100	38,000
Onshore wind power	32,700	11,000
Offshore wind power	17,000	4,200
Biopower[b]	500	62
Hydrothermal power systems	300	38
Enhanced geothermal systems	31,300	4,000
Hydropower	300	60

[a] Non-excluded land was assumed to be available to support development of more than one technology.
[b] All biomass feedstock resources considered were assumed to be available for biopower use; competing uses, such as biofuels production, were not considered.

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Introduction

Renewable energy technical potential, as defined in this study, represents the achievable energy generation of a particular technology given system performance, topographic limitations, environmental, and land-use constraints. The primary benefit of assessing technical potential is that it establishes an upper-boundary estimate of development potential (DOE EERE 2006). It is important to understand that there are multiple types of potential—resource, technical, economic, and market—each seen in Figure 1 with its key assumptions.

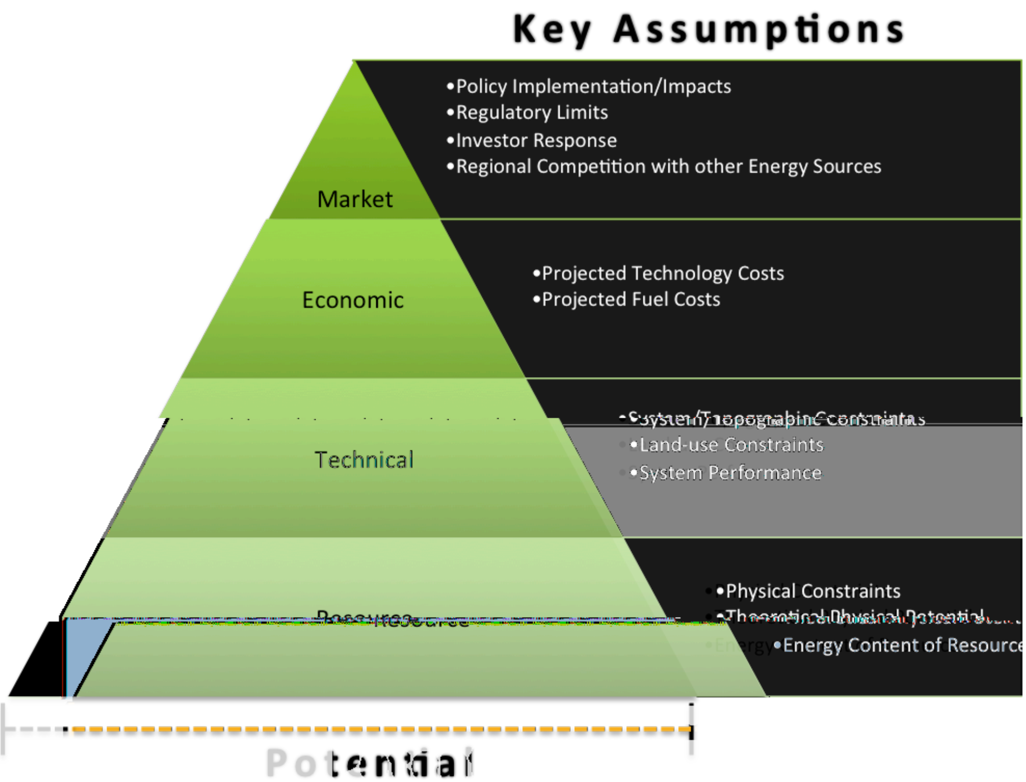

Figure 1. Levels of potential

Figure 1 is based on Table 4-1 in the 2011 update of DOE EERE (2006).

Although numerous studies have quantified renewable resource potential, comparing their results is difficult because of the different assumptions, methodologies, reporting units, and analysis time frames used (DOE EERE 2006). A national study of resource-based renewable energy technical potential across technologies has not been publicly available due to the challenges of unifying assumptions for all geographic areas and technologies (DOE EERE 2006).

This report presents the state-level results of a spatial analysis calculating renewable energy technical potential, reporting available land area (square kilometers), installed capacity (gigawatts), and electric generation (gigawatt-hours) for six different renewable electricity generation technologies: utility-scale photovoltaics (both urban and rural), concentrating solar power, onshore wind power, offshore wind power, biopower, and enhanced geothermal systems. Each technology's system-specific power density (or equivalent), capacity factor, and land-use constraints (Appendix A) were identified using published research, subject matter experts, and analysis by the National Renewable Energy Laboratory (NREL). System performance estimates rely heavily on NREL's Systems Advisor Model (SAM)[1] and Regional Energy Deployment System (ReEDS),[2] a multiregional, multi-time period, geographic information system (GIS) and linear programming model. This report also presents technical potential findings for rooftop photovoltaic, hydrothermal, and hydropower in a similar format based solely on previous published reports.

We provide methodological details of the analysis and references to the data sets used to ensure readers can directly assess the quality of data used, the data's underlying uncertainty, and impact of assumptions. While the majority of the exclusions applied for this analysis focus on evaluating technical potential, we include some economic exclusion criteria based on current commercial configuration standards to provide a more reasonable and conservative estimation of renewable resource potential.

Note that as a technical potential, rather than economic or market potential, these estimates do not consider availability of transmission infrastructure, costs, reliability or time-of-dispatch, current or future electricity loads, or relevant policies. Further, as this analysis does not allocate land for use by a particular technology, the same land area may be the basis for estimates of multiple technologies (i.e., non-excluded land is assumed to be available to support development of more than one technology).

Finally, since technical potential estimates are based in part on technology system performance, as these technologies evolve, their technical potential may also change.

[1] For more information, see http://sam.nrel.gov/.
[2] For more information, see http://www.nrel.gov/analysis/reeds/.

Analysis

Solar Power Technologies

Utility-Scale Photovoltaics (Urban)

We define urban utility-scale photovoltaics (PV) as large-scale PV deployed within urban boundaries on urban open space. The process for generating technical estimates for urban utility-scale PV begins with excluding areas not suitable for this technology. We first limit areas to those within urbanized area boundaries as defined by the U.S. Census Bureau (ESRI 2004) and further limit these areas to those with slopes less than or equal to 3%. Parking lots, roads, and urbanized areas are excluded by identifying areas with imperviousness greater than or equal to 1% (MRLC n.d.). Additional exclusions (Table A-1) are applied to eliminate areas deemed unlikely for development. The remaining land is grouped into contiguous areas and areas less than 18,000 square meters (m^2) are removed to ensure that total system size is large enough to be considered a utility-scale project.[3] This process produces a data set representative of the final available urban open space suitable for PV development. We obtain state-level annual capacity factors using the National Solar Radiation Database Typical Meteorological Year 3 (TMY3) data set (Wilcox, 2007; Wilcox and Marion, 2008) (Table A-2) and the SAM model. The PV system assumed in this analysis was a 1-axis tracking collector with the axis of rotation aligned north-south at 0 degrees tilt from the horizontal, which has a power density of 48 MW per square kilometer (MW/km^2) (Denholm and Margolis 2008a). State technical potential generation is expressed as:

$$State\ MWh = State\sum[urban\ openspace\ (km^2)\ \cdot power\ density\ \left(48\frac{MW}{km^2}\right) \cdot state\ capacity\ factor\ (\%) \cdot 8760\ (hours\ per\ year)]$$

Utility-Scale Photovoltaics (Rural)

We define rural utility-scale PV as large-scale PV deployed outside urban boundaries (the complement of urban utility-scale PV). Technical potential estimates for rural utility-scale PV begin by first excluding urban areas as defined by the U.S. Census Bureau's urbanized area boundaries data set. We calculate percent slope for areas outside the urban boundaries and eliminate all areas with slopes greater than or equal to 3%. Federally protected lands, inventoried roadless areas, and areas of critical environmental concern are also excluded, as they are considered unlikely areas for development. Table A-3 contains the full list of exclusions. To limit the available lands to only larger PV systems, a 1-km^2 contiguous area filter was applied to produce a final available land layer. Finally, we calculate technical potential energy generation for this available land with the same annual average capacity factors, system design, and power density as for urban utility-scale PV, expressed as:

$$State\ MWh = State\sum[available\ land\ (km^2)\ \cdot power\ density\ \left(48\frac{MW}{km^2}\right) \cdot state\ capacity\ factor\ (\%) \cdot 8760\ (hours\ per\ year)]$$

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[3] Depending on the PV system, 18,000 m^2 produces roughly a 1-MW system.

Rooftop Photovoltaics

We obtained rooftop PV estimates from Denholm and Margolis (2008b), who obtained floor space estimates for commercial and residential buildings from McGraw-Hill and scaled these to estimate a building footprint based on the number of floors. Average floor estimates were obtained from the Energy Information Administration's 2005 Residential Energy Consumption Survey (RECS) (DOE EIA 2005) and the 2003 Commercial Building Energy Consumption Survey (CBECS) (DOE EIA 2003). Denholm and Margolis (2008b) calculated roof footprint by dividing the building footprint by the number of floors. They estimated 8% of residential rooftops[4] and 63% of commercial rooftops[5] were flat. Orientations of pitched roofs were distributed uniformly. Usable roof area was extracted from total roof area using an availability factor that accounted for shading, rooftop obstructions, and constraints. Base estimates resulted in availability of 22% of roof areas for residential buildings in cool climates and 27% available in warm/arid climates. Denholm and Margolis (2008b) estimated commercial building availability at 60% for warm climates and 65% for cooler climates. Estimated average module efficiency was set at 13.5% with a power density for flat roofs of 110 W/m^2 and 135 W/m^2 for the rest. Denholm and Margolis (2008b) then aggregated state PV capacity to match Census Block Group populations; they then calculated capacity factors for the closest TMY station and applied these to the closest population group.

Concentrating Solar Power

We define concentrating solar power (CSP) as power from a utility-scale solar power facility in which the solar heat energy is collected in a central location. The technical potential estimates for CSP were calculated using satellite-modeled data from the National Solar Radiation Database (Wilcox, 2007), which represent annual average direct normal irradiance (DNI) as kilowatt-hours per square meter per day (kWh/m^2/day) from 1998 to 2005 at a 10-km horizontal spatial resolution. We consider viable only those areas with DNI greater than or equal to 5 kWh/m^2/day (Short et al. 2011).[6] Capacity factor values used in this analysis were generated for a trough system, dry-cooled with six hours of storage and a solar multiple[7] of 2, with a system power density of 32.8 MW/km^2.[8] The capacity factors for each resource class (Table A-4) are generated using the SAM model and TMY3. Land, slope, and contiguous area exclusions are consistent with rural utility-scale PV (Table A-3). Technical state energy generation was expressed as:

$$State\ MWh = State\sum\left[available\ land(km^2)\ \cdot power\ density\ \left(32.895\frac{MW}{km^2}\right) \cdot state\ capacity\ factor\ (\%) \cdot 8760\ (hours\ per\ year)\right]$$

[4] Based on estimates from Navigant Consulting
[5] Based on Commercial Building Energy Consumption Survey (CBECS) database
[6] Technology improvements may lead to improved performance in the future that could affect this threshold.
[7] The field aperture area expressed as a multiple of the aperture area required to operate the power cycle at its design capacity.
[8] Craig Turchi, NREL CSP Analyst, personal communication

Wind Power Technologies

Onshore Wind Power

We define onshore wind power as wind resource at 80 meters (m) height above surface that results in an annual average gross[9] capacity factor of 30% (net capacity factor of 25.5%), using typical utility-scale wind turbine power curves. AWS Truepower modeled the wind resource data using its Mesomap® process to produce estimates at a 200-m horizontal spatial resolution. These resource estimates are processed to eliminate areas unlikely to be developed, such as urban areas, federally protected lands, and onshore water features, Table A-5 includes a full list of exclusions. We estimate annual generation by assuming a power density of 5 MW/km^2 (DOE EERE 2008)[10] and 15% energy losses to calculate net capacity factor.[11]

Offshore Wind Power

We define suitable offshore wind resource as annual average wind speed greater than or equal to 6.4 meters per second (m/s) at 90 m height above surface.[12] The offshore wind resource data consists of a composite of data sets modeled to estimate offshore wind potential generated by AWS Truepower for the Atlantic Coast from Maine to Massachusetts, Texas, Louisiana, Georgia, and the Great Lakes. Other areas are included using near-shore estimates from onshore-modeled wind resources from published research (Schwartz et al. 2010). Because no offshore or near-shore estimates were available for Florida or Alaska (at the time of this publication), these states are omitted from the technical potential calculations. The offshore resource data extend 50 nautical miles from shore, and in some cases have to be extrapolated to fill the extent (Schwartz et al. 2010). We further filter the resource estimates to eliminate shipping lanes, marine sanctuaries, and a variety of other areas deemed unlikely to be developed. Table A-8 contains a full list of exclusions. Our annual generation estimates assume a power density of 5 MW/km^2 and capacity factors based on wind speed interval and depth-based wind farm configurations to account for anchoring and stabilization for the turbines as developed by NREL analysts for use in the ReEDS model (Musial and Ram 2010).

Biopower Technologies

Biopower (Solid and Gaseous)

We obtained county-level estimates of solid biomass resource for crop, forest, primary/secondary mill residues, and urban wood waste from Milbrandt (2005, updated in 2008)[13] who reported the estimates in bone-dry tonnes (BDT) per year. We calculate technical potential energy generation assuming 1.1 MWh/BDT, which represents an average solid biomass system output with an industry-average conversion efficiency of

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[9] Gross capacity factor does not include plant downtime, parasitic power, or other factors that would be included to reduce the output to the "Net" capacity factor.

[10] Represents total footprint; disturbed footprint ranges from 2% to 5% of the total

[11] For more information, see http://www.windpoweringamerica.gov/wind_maps.asp.

[12] This is a typical wind turbine hub-height for offshore wind developments.

[13] For more information, see http://www.nrel.gov/gis/biomass.html.

20%, and a higher heating value (HHV) of 8,500 BTU/lb (Ince 1979). From Milbrandt (2005, partially updated in 2008),[14] we obtained county-level estimates of gaseous biomass (methane emissions), from animal manure, domestic wastewater treatment plants, and landfills; all estimates were reported in tonnes of methane (CH_4) per year. We calculate technical potential energy generation assuming 4.7 MWh/tonne of CH_4, which represents a typical gaseous biomass system output with an industry-average conversion efficiency of 30% (Goldstein et al), and a HHV of 24,250 BTU/lb. Other biomass resources (such as orchard/vineyard pruning's and black liquor) were not included in this study due to data limitations. Also, this analysis assumed that all biomass resources considered were available for biopower and did not evaluate competing uses such as biofuels production. The data from Milbrandt (2005, updated in 2008)[15] illustrates the biomass resource currently available in the United States. Subsequent revisions of this analysis could evaluate projected U.S. resource potential, including dedicated energy crops such as those provided by the recent U.S. DOE update (DOE 2011) of the billion-ton study (Perlack et al. 2005).

Geothermal Energy Technologies

Hydrothermal Power Systems

For identified hydrothermal and undiscovered hydrothermal, we used estimates from Williams et al. (2008), who estimated electric power generation potential of conventional geothermal resources (hydrothermal), both identified and unidentified in the western United States, Alaska, and Hawaii. Williams et al. derived total potential for identified hydrothermal resources by state from summations of volumetric models for the thermal energy and electric generation potential of each individual geothermal system (Muffler, 1979). For undiscovered hydrothermal estimates, we used resource estimates generated by Williams et al. (2009) that used logistic regression models of the western United States to estimate favorability of hydrothermal development and thus, to estimate undiscovered potential. In all cases, exclusions included public lands, such as national parks, that are not available for resource development.

Enhanced Geothermal Systems

We derive technical potential estimates for enhanced geothermal systems (EGS)[16] from temperature at depth data obtained from the Southern Methodist University's (SMU) Geothermal Laboratory.[17] The data ranged from 3 km to 10 km in depth. We consider viable those regions at each depth interval with temperatures ≥150°C. We apply known potential electric capacity (MW_e/km^3) to each temperature-depth interval to estimate total potential at each depth interval based on the total volume of each unique temperature-

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[14] For more information, see http://www.nrel.gov/gis/biomass.html.

[15] For more information, see http://www.nrel.gov/gis/biomass.html.

[16] Deep enhanced geothermal systems (EGS) are an experimental method of extracting energy from deep within the Earth's crust. This is achieved by fracturing hot dry rock between 3 and 10 kilometers (km) below the Earth's surface and pumping fluid into the fracture. The fluid absorbs the Earth's internal heat and is pumped back to the surface and used to generate electricity.

[17] Maria Richards, SMU Geothermal Laboratory, e-mail message to author, May 29, 2009. Data set featured in *The Future of Geothermal Energy* (MIT 2006)

depth interval, shown in Table A-10. Electric generation potential calculations summarize the technical potential (MW) at all depth intervals, electric generation potential (GWh) at all depth intervals with a 90% capacity factor, and annual electric generation potential (GWh) only at optimum depth. We determine optimum depth by a quantitative analysis[18] of levelized cost of electricity (LCOE). An optimum depth is found because drilling costs increase with depth while temperature, and therefore power plant efficiency, generally increase with depth so that power plant costs decrease with depth. Because drilling costs are increasing while power plant costs are decreasing on a per-MW basis, at some point there is a minimum. The optimum depth assumes that the EGS reservoir has a height or thickness of 1 km.

Hydropower Technologies

Hydropower

Source point locations of hydropower estimates were provided by the Idaho National Laboratory and were taken from Hall et al. (2006). The point locations were based on a previous study (Hall et al. 2004) that produced an assessment of gross power potential of every stream in the United States. To generate their own estimates, Hall et al. developed and used a feasibility study and development model. The feasibility study included additional economic potential criteria such as site accessibility, load or transmission proximity, along with technical potential exclusions of land use or environmental sensitivity. Sites meeting Hall et al. (2006) feasibility criteria were processed to produce power potential using a development model that did not require a dam or reservoir be built. The development model assumed only a low power (<1 MWa) or small hydro (>= 1 MWa and <= 30 MWa) plant would be built. To produce state technical potentials, we aggregated the previously mentioned source point locations to the state level.

[18] We used the quantitative analysis method from Augustine (2011).

Results

For each technology, we provide a brief summary of our findings along with a figure (map) showing the total estimated technical potential for all states and a table listing the total estimated technical potential by state.

Solar Power Technologies

Utility-Scale PV (Urban)

The total estimated annual technical potential in the United States for urban utility-scale PV is 2,232 terawatt-hours (TWh). Texas and California have the highest estimated technical potential, a result of a combination of good solar resource and large population. Figure 2 and Table 2 present the total estimated technical potential for urban utility-scale PV.

Utility-Scale PV (Rural)

Rural utility-scale PV leads all other technologies in technical potential. This is a result of relatively high power density, the absence of minimum resource threshold, and the availability of large swaths for development. Texas accounts for roughly 14% (38,993 TWh) of the entire estimated U.S. technical potential for utility-scale PV (280,613 TWh). Figure 3 and Table 3 present the total estimated technical potential for rural utility-scale PV.

Rooftop PV

Total annual technical potential for rooftop PV is estimated at 818 TWh. States with the largest technical potential typically have the largest populations. California has the highest technical potential of 106 TWh due to its mix of high population and relatively good solar resource. Figure 4 and Table 4 present the total estimated technical potential for rural utility-scale PV.

Concentrating Solar Power

Technical potential for CSP exists predominately in the Southwest. The steep cutoff of potential, as seen in Figure 5, can be attributed to the resource minimum threshold of 5 kWh/m2/day that was used in the analysis. Texas has the highest estimated potential of 22,786 TWh, which accounts for roughly 20% of the entire estimated U.S. annual technical potential for CSP (116,146 TWh). Figure 5 and Table 5 present the total estimated technical potential for concentrating solar power.

Wind Power Technologies

Onshore Wind Power

Technical potential for onshore wind power, which is present in nearly every state, is largest in the western and central Great Plains and lowest in the southeastern United States. While the wind resource intensity in the Great Plains is not as high as it is in some areas of the western United States, very little of the land area is excluded due to insufficient resource or due to other exclusions. In the eastern and western United States, the wind resource is more limited in coverage and is more likely to be impacted by environmental exclusions. Texas has the highest estimated annual potential of 5,552 TWh, which accounts for roughly 17% of the entire estimated U.S. annual technical potential for onshore wind (32,784 TWh). Figure 6 and Table 6 present the total estimated technical potential for onshore wind power.

Offshore Wind Power

Technical potential for offshore wind power is present in significant quantities in all offshore regions of the United States. Wind speeds off the Atlantic Coast and in the Gulf of Mexico are lower than they are off the Pacific Coast, but the presence of shallower waters there makes these regions more attractive for development. Hawaii has the highest estimated annual potential of 2,837 TWh, which accounts for roughly 17% of the entire estimated U.S. annual technical potential for offshore wind (16,975 TWh). Figure 7 and Table 7 present the total estimated technical potential for offshore wind power.

Biopower Technologies

Biopower (Solid and Gaseous)

Solid biomass accounts for 82% of the 400 TWh total estimated annual technical potential of biopower; of that, crop residues are the largest contributor. Gaseous biomass has an estimated annual technical potential of 88 TWh, of which landfills were the largest contributor. Figure 8 and Table 8 present the total estimated technical potential for biopower.

Geothermal Energy Technologies

Hydrothermal Power Systems

In the assessment, 71 TWh of electric power generation potential is the estimated total from existing (identified) hydrothermal sites spread among 13 states. An additional 237 TWh of undiscovered hydrothermal resources are estimated to exist among these same states. Figure 9 and Table 9 present the total estimated technical potential for hydrothermal power systems.

Enhanced Geothermal Systems

The vast majority of the geothermal potential for EGS (31,344 TWh) within the contiguous United States is located in the westernmost portion of the country. The Rocky Mountain States, and the Great Basin particularly, contain the most favorable resource for EGS (17,414 TWh). However, even the central and eastern portions of the country have 13,930 TWh of potential for EGS development. Note that, especially in western states, a considerable portion of the EGS resource occurs on protected land and was filtered out after exclusions were applied. Figure 10 and Table 10 present the total estimated technical potential for enhanced geothermal systems.

Hydropower Technologies

Hydropower

According to Hall et al. (2006), technical potential for hydropower exists predominately in the Northwest and Alaska with a combined total estimated at 69 TWh annually, which accounts for roughly 27% of the entire estimated U.S. annual technical potential for hydropower (259 TWh). Figure 11 and Table 11 present the total estimated technical potential for hydropower.

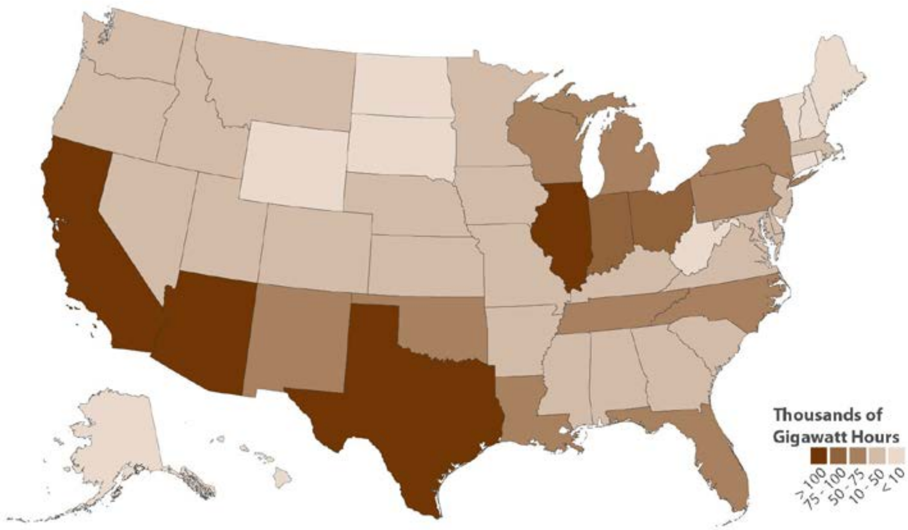

Figure 2. Total estimated technical potential for urban utility-scale photovoltaics in the United States

Table 2. Total Estimated Technical Potential for Urban Utility-Scale Photovoltaics by State[a]

State	KM^2	GW	GWh		State	KM^2	GW	GWh
Alabama	426	20	35,851		Montana	127	6	11,371
Alaska	2	<1	166		Nebraska	142	7	12,954
Arizona	1,096	53	121,306		Nevada	225	11	24,894
Arkansas	332	16	28,961		New Hampshire	49	2	3,790
California	2,321	111	246,008		New Jersey	527	25	44,307
Colorado	[illegible]	[illegible]	[illegible]		New Mexico	[illegible]	[illegible]	71,356
Connecticut	101	5	7,717		New York	683	33	52,803
Delaware	190	9	14,856		North Carolina	789	38	68,346
District of Columbia	<1	<1	8		North Dakota	57	3	4,871
Florida	830	40	72,787		Ohio	1,190	57	86,496
Georgia	[illegible]	[illegible]	[illegible]		Oklahoma	[illegible]	[illegible]	[illegible]
Hawaii	35	2	3,725		Oregon	271	13	25,783
Idaho	251	12	23,195		Pennsylvania	754	36	56,162
Illinois	1,325	64	103,552		Rhode Island	24	1	1,788
Indiana	1,274	61	98,815		South Carolina	398	19	33,835
Iowa	324	16	27,092		South Dakota	51	2	4,574
Kansas	317	15	31,706		Tennessee	596	29	50,243
Kentucky	[illegible]	16	[illegible]		Texas	[illegible]	[illegible]	[illegible]
Louisiana	675	32	55,669		Utah	293	14	30,492
Maine	40	2	3,216		Vermont	22	1	1,632
Maryland	[illegible]	[illegible]	[illegible]		Virginia	[illegible]	[illegible]	[illegible]
Massachusetts	[illegible]	[illegible]	[illegible]		Washington	[illegible]	[illegible]	[illegible]
Michigan	699	34	50,845		West Virginia	42	2	3,024
Minnesota	[illegible]	[illegible]	[illegible]		Wisconsin	[illegible]	[illegible]	[illegible]
Mississippi	318	15	26,366		Wyoming	75	4	7,232
Missouri	377	18	30,549		U.S. Total	25,369	[illegible]	2,231,694

[a] Non-excluded land was assumed to be available to support development of more than one technology.

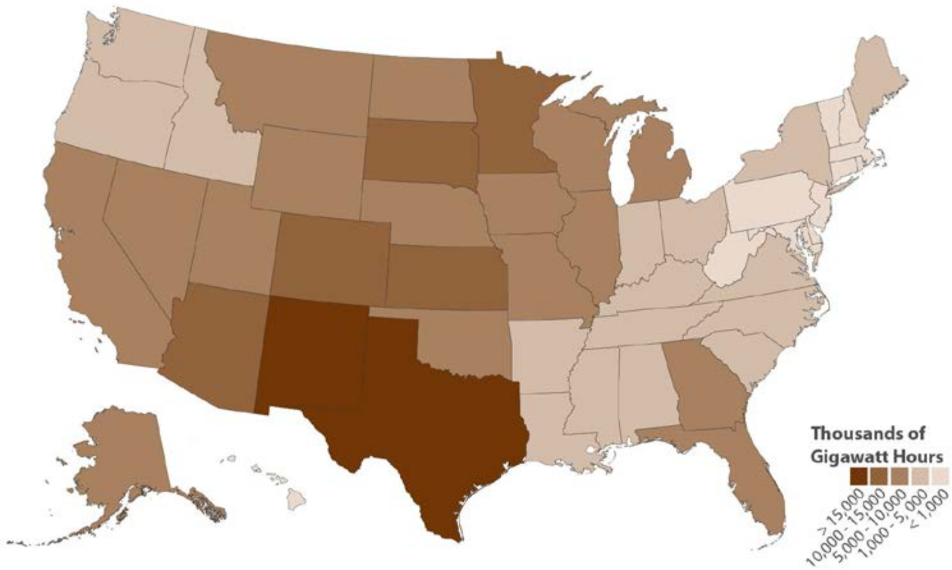

Figure 3. Total estimated technical potential for rural utility-scale photovoltaics in the United States

Table 3. Total Estimated Technical Potential for Rural Utility-Scale Photovoltaics by State[a]

State	KM²	GW	GWh		State	KM²	GW	GWh	
Alabama	44,058	2,115	3,706,839		Montana	91,724	4,403	8,187,341	
	101,457	4,870	[illegible]	Alaska	187,608	[illegible]	[illegible]		Nebraska
	77,751	3,732	8,614,454	Arizona	107,231	5,147	11,867,694		Nevada
re	741	36	57,364	Arkansas	57,239	2,747	4,986,389		New Hampshi
	5,232	251	439,774	California	83,549	4,010	8,855,917		New Jersey
	147,652	7,087	16,318,543	Colorado	94,046	4,514	10,238,084		New Mexico
	19,294	926	1,492,566	Connecticut	256	12	19,628		New York
a	48,892	2,347	4,232,790	Delaware	3,483	167	272,333		North Carolin
	114,228	5,483	9,734,448	District of Columbia	0	0	0		North Dakota
	49,908	2,396	3,626,182	Florida	58,597	2,813	5,137,347		Ohio
	99,641	4,783	9,341,920	Georgia	64,343	3,088	5,492,183		Oklahoma
	39,267	1,885	3,740,479	Hawaii	431	21	38,033		Oregon
	7,430	357	553,356	Idaho	42,613	2,045	3,936,848		Pennsylvania
	184	9	13,636	Illinois	103,524	4,969	8,090,985		Rhode Island
	32,399	1,555	2,754,973	Indiana	62,891	3,019	4,876,186		South Carolina
	111,350	5,345	10,008,873	Iowa	83,763	4,021	[illegible]		South Dakota
	26,396	1,267	2,225,990	Kansas	144,996	6,960	14,500,149		Tennessee
	425,230	20,411	38,993,582	Kentucky	23,319	1,119	1,823,977		Texas
	49,797	2,390	5,184,878	Louisiana	49,876	2,394	4,114,605		Utah
	739	35	54,728	Maine	13,723	659	1,100,327		Vermont
	22,378	1,074	1,882,467	Maryland	7,773	373	585,949		Virginia
	20,759	996	1,738,151	Massachusetts	1,074	52	82,205		Washington
	729	35	52,694	Michigan	71,741	3,444	5,215,640		West Virginia
	66,788	3,206	5,042,259	Minnesota	135,627	6,510	10,792,814		Wisconsin
	59,464	2,854	5,727,224	Mississippi	59,997	2,880	4,981,252		Wyoming
	3,186,955	152,974	280,613,217	Missouri	65,767	3,157	5,335,269		U.S. Total

[a] Non-excluded land was assumed to be available to support development of more than one technology.

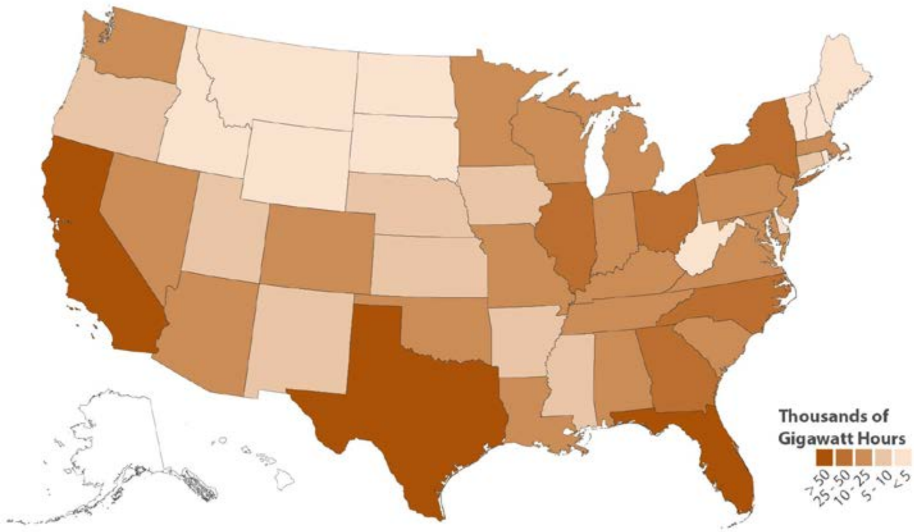

Figure 4. Total estimated technical potential for rooftop photovoltaics in the United States

Table 4. Total Estimated Technical Potential for Rooftop Photovoltaics by State[a]

State	GW	GWh	State	GW	GWh
Alabama	13	15,476	Montana	2	2,194
Alaska	1	NA	Nebraska	4	5,337
Arizona	15	22,736	Nevada	7	[illegible]
New Hampshire	2	2,299	Arkansas	[illegible]	[illegible]
New Jersey	14	15,768	California	76	106,411
New Mexico	4	6,513	Colorado	12	16,162
New York	25	28,780	Connecticut	6	6,616
North Carolina	23	28,420	Delaware	2	2,185
North Dakota	2	1,917	District of Columbia	2	2,490
Ohio	27	30,064	Florida	49	63,987
Oklahoma	9	12,443	Georgia	25	31,116
Oregon	8	8,323	Hawaii	3	NA
Pennsylvania	20	22,215	Idaho	3	4,051
Rhode Island	[illegible]	1,711	Illinois	[illegible]	[illegible]
South Carolina	13	[illegible]	Indiana	15	17,151
South Dakota	2	2,083	Iowa	7	[illegible]
Tennessee	16	19,685	Kansas	7	8,962
Texas	60	78,717	Kentucky	11	12,312
Utah	6	7,514	Louisiana	12	14,368
Vermont	1	1,115	Maine	2	2,443
Virginia	19	22,267	Maryland	13	14,850
Washington	13	13,599	Massachusetts	10	11,723
West Virginia	4	4,220	Michigan	22	23,528
Wisconsin	12	13,939	Minnesota	12	14,322
Wyoming	1	1,551	Mississippi	7	[illegible]
U.S. Total	[illegible]	[illegible]	Missouri	[illegible]	[illegible]

[a] Non-excluded land was assumed to be available to support development of more than one technology.

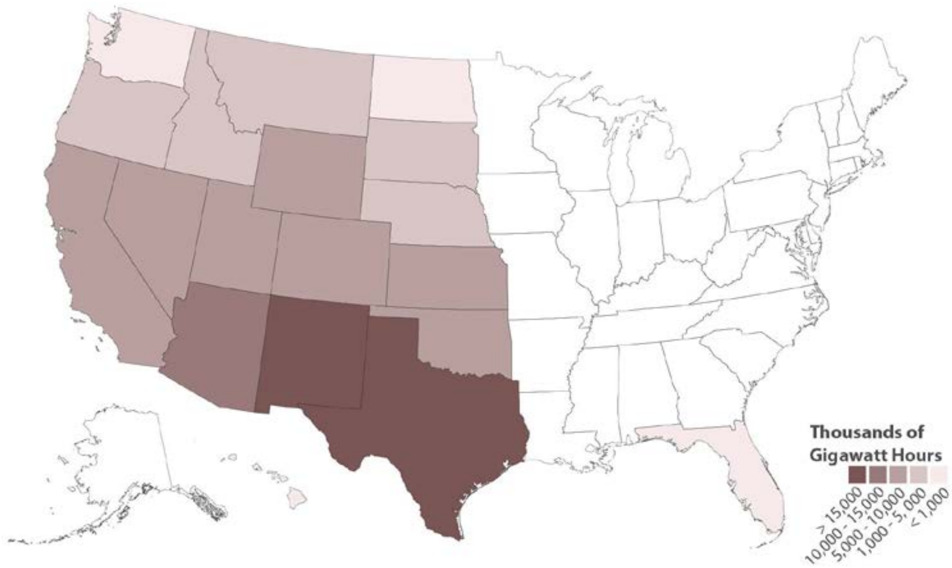

Figure 5. Total estimated technical potential for concentrating solar power in the United States

Table 5. Total Estimated Technical Potential for Concentrating Solar Power by State[a]

State	KM²	GW	GWh		State	KM²	GW	GWh
Alabama	0	0	0		Montana	16,939	557	1,540,288
Alaska	0	0	0		Nebraska	53,305	1,753	4,846,929
Arizona	107,239	3,528	12,544,334		Nevada	77,760	2,558	8,295,753
Arkansas	0	0	0		New Hampshire	0	0	0
California	82,860	2,726	8,490,916		New Jersey	0	0	0
Colorado	94,173	3,098	9,154,524		New Mexico	147,748	4,860	16,812,349
Connecticut	0	0	0		New York	0	0	0
Delaware	0	0	0		North Carolina	0	0	0
District of Columbia	0	0	0		North Dakota	396	13	36,050
Florida	4	0	359		Ohio	0	0	0
Georgia	0	0	0		Oklahoma	55,113	1,813	[illegible]
Hawaii	168	6	15,370		Oregon	30,927	1,017	2,812,126
Idaho	38,523	1,267	3,502,877		Pennsylvania	0	0	0
Illinois	0	0	0		Rhode Island	0	0	0
Indiana	0	0	0		South Carolina	0	0	0
Iowa	0	0	0		South Dakota	17,922	590	1,629,660
Kansas	[illegible]	[illegible]	[illegible]		Tennessee	[illegible]	[illegible]	[illegible]
Kentucky	0	0	0		Texas	235,398	7,743	22,786,750
Louisiana	[illegible]	[illegible]	[illegible]		Utah	[illegible]	[illegible]	[illegible]
Maine	0	0	0		Vermont	0	0	0
Maryland	0	0	0		Virginia	0	0	0
Massachusetts	0	0	0		Washington	1,778	59	161,713
Michigan	0	0	0		West Virginia	0	0	0
Minnesota	[illegible]	[illegible]	[illegible]		Wisconsin	[illegible]	[illegible]	[illegible]
Mississippi	0	0	0		Wyoming	59,457	1,956	5,406,407
Missouri	0	0	0		U.S. Total	1,157,200	38,066	116,146,245

[a] Non-excluded land was assumed to be available to support development of more than one technology.

Figure 6. Total estimated technical potential for onshore wind power in the United States

Table 6. Total Estimated Technical Potential for Onshore Wind Power by State[a]

State	KM²	GW	GWh		State	KM²	GW	GWh
Alabama	24	<1	283		Montana	188,801	944	2,746,272
Alaska	98,669	493	1,373,433		Nebraska	183,600	918	3,011,253
Arizona	2,181	11	26,036		Nevada	1,449	7	17,709
Arkansas	1,840	9	22,892		New Hampshire	427	2	5,706
California	6,822	34	89,862		New Jersey	26	<1	317
[illegible]	[illegible]	[illegible]	[illegible]		New Mexico	[illegible]	[illegible]	[illegible]
Connecticut	5	<1	62		New York	5,156	26	63,566
Delaware	[illegible]	[illegible]	[illegible]		North Carolina	163	<1	2,037
District of Columbia	0	0	0		North Dakota	154,039	770	2,537,825
Florida	<1	<1	<1		Ohio	10,984	55	129,143
Georgia	26	<1	323		Oklahoma	103,364	517	1,521,652
Hawaii	494	2	7,787		Oregon	5,420	27	68,767
Idaho	3,615	18	44,320		Pennsylvania	661	3	8,231
Illinois	49,976	250	649,468		Rhode Island	9	<1	130
Indiana	29,646	148	377,604		South Carolina	37	<1	428
Iowa	[illegible]	[illegible]	[illegible]		South Dakota	[illegible]	[illegible]	[illegible]
Kansas	190,474	952	3,101,576		Tennessee	62	<1	766
Kentucky	12	<1	147		Texas	380,306	1,902	5,552,400
Louisiana	82	<1	935		Utah	2,621	13	31,552
Maine	2,250	11	28,743		Vermont	590	3	7,796
Maryland	297	1	3,632		Virginia	359	2	4,589
Massachusetts	[illegible]	[illegible]	[illegible]		Washington	[illegible]	18	[illegible]
Michigan	11,808	59	143,908		West Virginia	377	2	[illegible]
Minnesota	97,854	489	1,428,525		Wisconsin	20,751	104	[illegible]
Mississippi	0	0	0		Wyoming	110,415	552	[illegible]
Missouri	54,871	274	689,519		U.S. Total	2,190,952	10,955	[illegible]

[a] Non-excluded land was assumed to be available to support development of more than one technology.

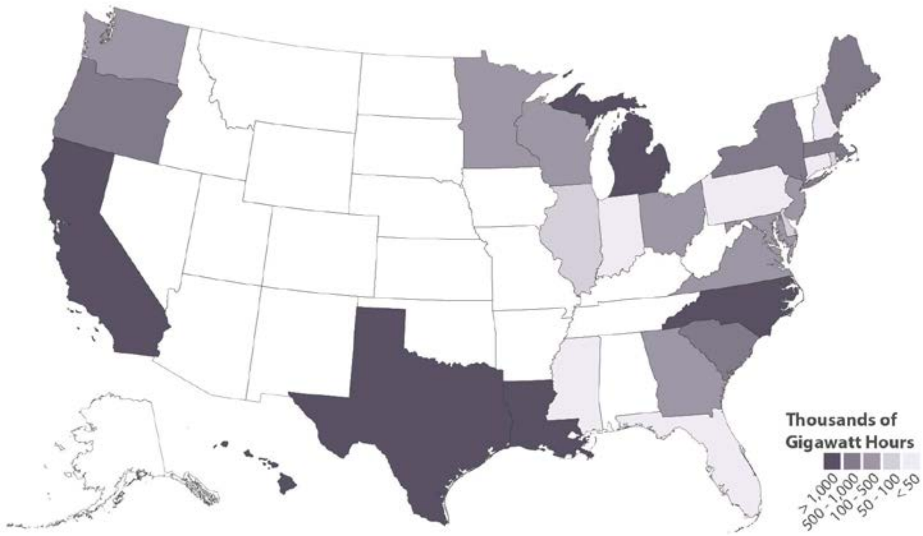

Figure 7. Total estimated technical potential for offshore wind power in the United States

Table 7. Total Estimated Technical Potential for Offshore Wind Power by State[a]

State	KM^2	GW	GWh		State	KM^2	GW	GWh
Alabama	0	0	0		Montana	NA	NA	NA
[illegible]	NA	NA	NA		Nebraska	NA	NA	NA
NA Arizona	NA	NA	NA		Nevada	NA	NA	
4,478 Arkansas	NA	NA	NA		New Hampshire	691	3	1
9,808 California	130,967	655	2,662,580		New Jersey	20,387	102	42
NA Colorado	NA	NA	NA		New Mexico	NA	NA	
4,280 Connecticut	1,434	7	26,545		New York	29,215	146	61
Delaware	3,008	15	60,654		North Carolina	61,204	306	[illegible]
District of Columbia	NA	NA	NA		North Dakota	NA	NA	NA
Florida	1,930	10	34,684		Ohio	8,361	42	170,561
Georgia	11,726	59	220,807		Oklahoma	NA	NA	NA
Hawaii	[illegible]	[illegible]	[illegible]		Oregon	[illegible]	[illegible]	[illegible]
Idaho	NA	NA	NA		Pennsylvania	1,135	6	23,571
Illinois	3,174	16	66,070		Rhode Island	4,193	21	89,115
Indiana	9	<1	166		South Carolina	26,643	133	542,218
[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]
NA NA Kansas	NA	NA	NA		Tennessee	NA		
271 1,101,063 Kentucky	NA	NA	NA		Texas	54,289		
NA NA Louisiana	68,123	341	1,200,699		Utah	NA		
[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]
17,815 89 361,054 Maryland	10,382	52	200,852		Virginia			
24,193 121 488,025 Massachusetts	36,815	184	799,344		Washington			
[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]

[redacted]

[a] Non-excluded land was assumed to be available to support development of more than one technology.

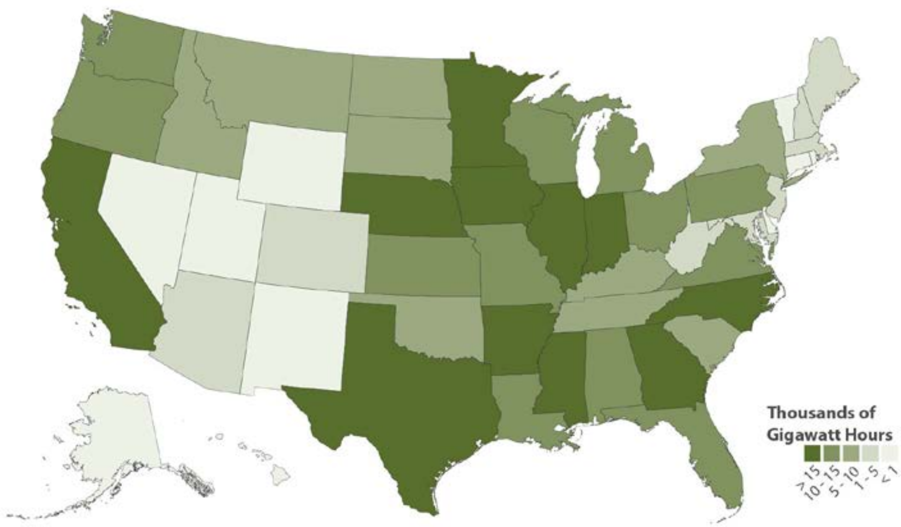

Figure 8. Total estimated technical potential for biopower in the United States

Table 8. Total Estimated Technical Potential for Biopower by State[a]

State	GW	GWh		State	GW	GWh	
Alabama	2	12,727		Montana	<1	5,072	
Alaska	<1	575		Nebraska	2	17,023	
Arizona	<1	1,925		Nevada	<1	614	
Arkansas	2	[illegible]		New Hampshire	<1	[illegible]	
<1	3,523	California	4	27,919		New Jersey	
<1	949	Colorado	<1	4,138		New Mexico	
1	8,509	Connecticut	<1	909		New York	
2	16,650	Delaware	<1	898		North Carolina	
1	8,216	District of Columbia	<1	66		North Dakota	
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	
<1	5,094	Georgia	2	16,903		Oklahoma	
2	14,684	Hawaii	<1	724		Oregon	
2	13,446	Idaho	<1	5,958		Pennsylvania	
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	
th Carolina	1	8,415	Indiana	2	17,920		Sou
th Dakota	1	8,615	Iowa	4	28,928		Sou
nnessee	[illegible]	[illegible]	Kansas	[illegible]	[illegible]		Te
xas	3	21,976	Kentucky	1	8,322		Te
ah	<1	862	Louisiana	2	14,873		Ut
rmont	<1	695	Maine	<1	4,398		Ve
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		Vi
2,149		Washington	2	13,826	Massachusetts	<1	
1,897		West Virginia	<1	2,688	Michigan	2	1
1,391		Wisconsin	2	13,295	Minnesota	3	2
[illegible]	[illegible]	Wyoming	[illegible]	[illegible]	Mississippi	[illegible]	
2	13,986		U.S. Total	62	488,326	Missouri	

[a] Non-excluded land was assumed to be available to support development of more than one technology. All biomass feedstock resources considered were assumed to be available for biopower use; competing uses, such as biofuels production, were not considered.

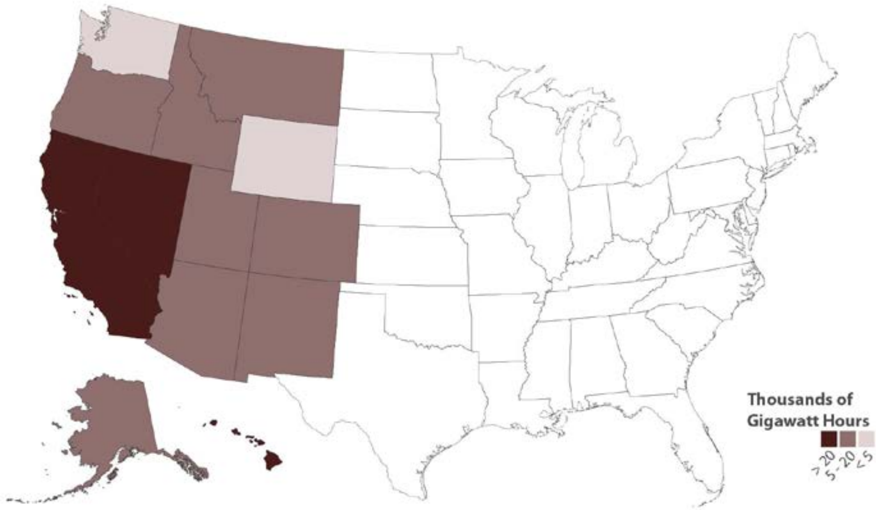

Figure 9. Total estimated technical potential for hydrothermal power in the United States

Table 9. Total Estimated Technical Potential for Hydrothermal Power by State[a]

	State	GW	GWh		State	GW	GWh
	Alabama	[illegible]	<1		Montana	<1	[illegible]
	Alaska	2	15,437		Nebraska	<1	[illegible]
	Arizona	[illegible]	[illegible]	[illegible]	Nevada	[illegible]	[illegible]
<1	Arkansas	<1	<1		New Hampshire	<1	
<1	California	17	130,921		New Jersey	<1	
12,933	Colorado	1	8,954		New Mexico	2	
<1	Connecticut	<1	<1		New York	<1	
[illegible]	Delaware	[illegible]	[illegible]		North Carolina	[illegible]	
1	District of Columbia	<1	<1		North Dakota	<1	[illegible]
<1	Florida	<1	<1		Ohio	<1	
<1	Georgia	<1	<1		Oklahoma	<1	
200	Hawaii	3	20,632		Oregon	2	18,[illegible]
[illegible]	Idaho	[illegible]	[illegible]		Pennsylvania	[illegible]	
[illegible]	Illinois	[illegible]	[illegible]		Rhode Island	[illegible]	
<1	Indiana	<1	<1		South Carolina	<1	
<1	Iowa	<1	<1		South Dakota	<1	
<1	Kansas	<1	<1		Tennessee	<1	
<1	Kentucky	<1	<1		Texas	<1	
[illegible]	Louisiana	[illegible]	[illegible]		Utah	[illegible]	
<1	Maine	<1	<1		Vermont	<1	
<1	Maryland	<1	<1		Virginia	<1	
2,547	Massachusetts	<1	<1		Washington	<1	
<1	Michigan	<1	<1		West Virginia	<1	
<1	Minnesota	<1	<1		Wisconsin	<1	
1,373	Mississippi	<1	<1		Wyoming	<1	
308,156	Missouri	<1	<1		**U.S. Total**	**38**	

[a] Non-excluded land was assumed to be available to support development of more than one technology.

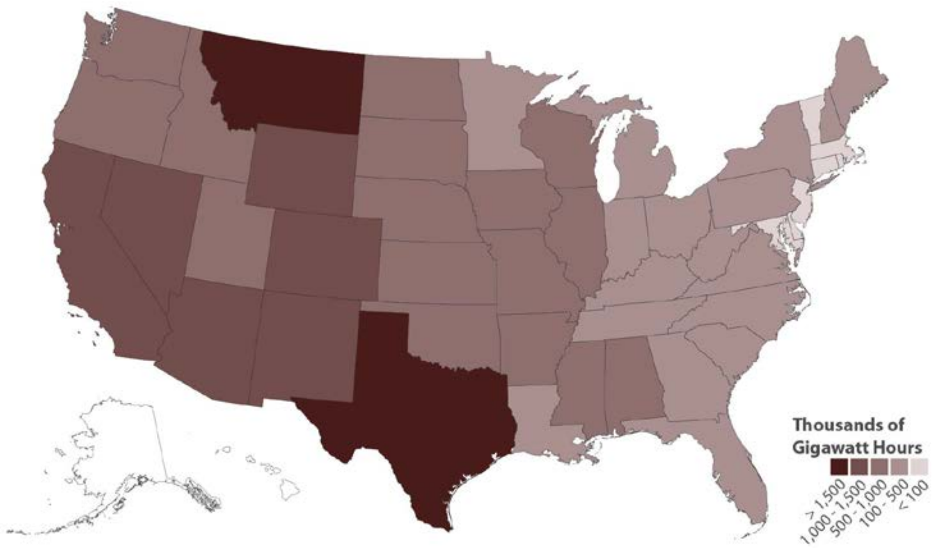

Figure 10. Total estimated technical potential for enhanced geothermal systems in the United States

Table 10. Total Estimated Technical Potential for Enhanced Geothermal Systems by State[a]

State	GW	GWh		State	GW	GWh	
Alabama	68	535,490		Montana	209	1,647,304	
Alaska	NA	NA		Nebraska	118	927,996	
[illegible] Arizona	[illegible]	[illegible] 1,239,148		Nevada	[illegible]	[illegible]	
4,314	Arkansas	80	628,622		New Hampshire	13	10
5,230	California	170	1,344,179		New Jersey	4	3
7,978	Colorado	159	1,251,658		New Mexico	180	1,41
[illegible]	Connecticut	[illegible]	[illegible]	New York	[illegible]	[illegible]	Connecticut
3	22,813		North Carolina	53	420,741	Delaware	
<1	698		North Dakota	104	820,226	District of Columbia	
47	374,161		Ohio	63	495,922	Florida	
45	353,206		Oklahoma	99	779,667	Georgia	
NA	NA		Oregon	116	914,105	Hawaii	
126	993,257		Pennsylvania	42	327,341	Idaho	
86	676,056		Rhode Island	1	11,492	Illinois	
55	434,258		South Carolina	46	364,105	Indiana	
77	606,390		South Dakota	117	921,973	Iowa	
126	989,676		Tennessee	54	428,380	Kansas	
61	484,659		Texas	384	3,030,251	Kentucky	
61	484,271		Utah	119	939,381	Louisiana	
48	377,075		Vermont	5	35,617	Maine	
11	86,649		Virginia	37	290,737	Maryland	
12	92,227		Washington	71	563,024	Massachusetts	
58	457,850		West Virginia	33	261,376	Michigan	
47	369,785		Wisconsin	82	647,173	Minnesota	
71	559,056		Wyoming	136	1,070,079	Mississippi	
106	835,445		**U.S. Total**	**3,976**	**31,344,696**	Missouri	

[a] Non-excluded land was assumed to be available to support development of more than one technology.

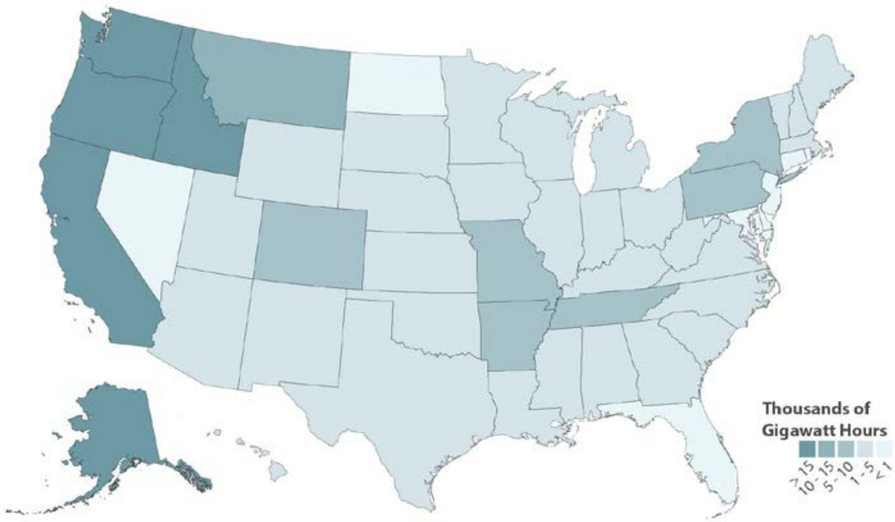

Figure 11. Total estimated technical potential for hydropower in the United States

Table 11. Total Estimated Technical Potential for Hydropower by State[a]

State	Count	GW	GWh		State	Count	GW	GWh
Alabama	2,435	<1	4,103		Montana	6,859	3	14,547
Alaska	3,053	5	23,676		Nebraska	2,880	<1	3,142
Arizona	1,958	<1	1,303		Nevada	1,489	<1	846
Arkansas	3,268	1	6,093		New Hampshire	810	<1	1,741
<1	549	California	9,692	7	30,024		New Jersey	402
<1	1,363	Colorado	5,060	2	7,789		New Mexico	1,810
2	6,711	Connecticut	659	<1	922		New York	4,839
<1	3,037	Delaware	25	<1	31		North Carolina	2,131
<1	347	District of Columbia	2	<1	<1		North Dakota	572
<1	3,046	Florida	493	<1	682		Ohio	1,791
<1	3,016	Georgia	2,100	<1	1,988		Oklahoma	2,824
4	18,184	Hawaii	437	<1	2,602		Oregon	7,993
2	8,368	Idaho	6,706	4	18,758		Pennsylvania	4,466
<1	[illegible]	Illinois	[illegible]	[illegible]	[illegible]		Rhode Island	[illegible]
<1	1,889	Indiana	1,142	<1	2,394		South Carolina	889
<1	1,047	Iowa	2,398	<1	2,818		South Dakota	1,712
1	5,745	Kansas	3,201	<1	2,508		Tennessee	2,610
<1	3,006	Kentucky	1,394	<1	4,255		Texas	4,366
<1	3,528	Louisiana	934	<1	2,423		Utah	3,394
[illegible]	[illegible]	Maine	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]
2,601	<1	3,657	Maryland	491	<1	814		Virginia
7,310	6	27,249	Massachusetts	560	<1	1,197		Washington
1,711	1	4,408	Michigan	1,942	<1	1,181		West Virginia
1,863	1	2,287	Minnesota	1,391	<1	1,255		Wisconsin
2,842	1	4,445	Mississippi	1,536	<1	2,211		Wyoming
[illegible]	[illegible]	[illegible]	Missouri	[illegible]	[illegible]	[illegible]		U.S. Totals

[a] Non-excluded land was assumed to be available to support development of more than one technology.

Discussion

Table 12 summarizes the estimated technical generation and capacity potential in the Unites States for each renewable electricity technology examined in this report. As estimates of technical, rather than economic or market, potential, these values do not consider:

- Allocation of available land among technologies (available land is generally assumed to be available to support development of more than one technology and each set of exclusions was applied independently)
- Availability of existing or planned transmission infrastructure that is necessary to tie generation into the electricity grid
- The relative reliability or time-of-productions of power
- The cost associated with developing power at any location
- Presence of local, state, regional or national policies, either existing or potential, that could encourage renewable development
- The location or magnitude of current and potential electricity loads.

While not a direct comparison, given the above considerations, one useful point of reference for the generation potential estimate is annual electricity retail sales in the United States. In 2010, aggregate sales for all 50 states were roughly 3,754 TWh (see Appendix B).

Table 12. Total Estimated Technical Potential Generation and Capacity by Technology

Technology	Generation Potential (TWh)[a]	Capacity Potential (GW)[a]
Urban utility-scale PV	2,200	1,200
Rural utility-scale PV	280,600	153,000
Rooftop PV	800	664
Concentrating solar power	116,100	38,000
Onshore wind power	32,700	11,000
Offshore wind power	17,000	4,200
Biopower[b]	500	62
Hydrothermal power systems	300	38
Enhanced geothermal systems	31,300	4,000
Hydropower	300	60

[a] Non-excluded land was assumed to be available to support development of more than one technology.
[b] All biomass feedstock resources considered were assumed to be available for biopower use; competing uses, such as biofuels production, were not considered.

Updates to these technical potentials are possible on an ongoing basis as resource, system, exclusions and domain knowledge change and data sets improve in quality and resolution. In this study, we identified areas of potential improvements that include the acquisition of localized PV capacity factors, updated exclusion layers, and the use of updated land-cover data sets.

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Appendix A. Exclusions and Constraints, Capacity Factors, and Power Densities

Table A-1. Exclusions and Constraints for Urban Utility-Scale Photovoltaics

Slope Exclusion	> 3%	
Contiguous Area Exclusion	< 0.018 km^2	
Land Type(s) Exclusion	Within Urban Boundaries	ESRI (2004)
	Landmarks	ESRI (2007a)
	Parks	ESRI (2007b)
	MRLC - Water	MRLC (n.d.)
	MRLC - Wetlands	MRLC (n.d.)
	MRLC - Forests	MRLC (n.d.)
	MRLC -Impervious Surface >= 1%	MRLC (n.d.)

Table A-2. Capacity Factors for Utility-Scale Photovoltaics[a]

State	Capacity Factor	State	Capacity Factor	State	Capacity Factor
Alabama	0.200	Maine	0.191	Oklahoma	0.223
Alaska	0.105	Maryland	0.179	Oregon	0.227
Arizona	0.263	Massachusetts	0.182	Pennsylvania	0.177
Arkansas	0.207	Michigan	0.173	Rhode Island	0.176
California	0.252	Minnesota	0.189	South Carolina	0.202
Colorado	0.259	Mississippi	0.197	South Dakota	0.214
Connecticut	0.182	Missouri	0.193	Tennessee	0.201
Delaware	0.186	Montana	0.212	Texas	0.218
Florida	0.209	Nebraska	0.217	Utah	0.248
Georgia	0.203	Nevada	0.263	Vermont	0.176
Hawaii	0.210	New Hampshire	0.184	Virginia	0.200
Idaho	0.220	New Jersey	0.200	Washington	0.199
Illinois	0.186	New Mexico	0.263	West Virginia	0.172
Indiana	0.184	New York	0.184	Wisconsin	0.180
Iowa	0.199	North Carolina	0.206	Wyoming	0.229
Kansas	0.238	North Dakota	0.203		
Kentucky	0.186	Ohio	0.173		
Louisiana	0.196				

[a] (SAM)

Table A-3. Exclusions and Constraints for Rural Utility-Scale Photovoltaics and Concentrating Solar Power

Slope Exclusion	> 3%	
Contiguous Area Exclusion	< 1 km^2	
Land Type(s) Exclusion	Urban Areas	ESRI (2004)
	MRLC - Water	MRLC (n.d.)
	MRLC - Wetlands	MRLC (n.d.)
	BLM ACEC Lands (Areas of Critical Environmental Concern) (BLM 2009)	BLM (2009)
	Forest Service IRA (Inventoried Roadless Area) (USFS 2003)	USFS (2003)
	National Park Service Lands	USGS (2005)
	Fish & Wildlife Lands	USGS (2005)
	Federal Parks	USGS (2005)
	Federal Wilderness	USGS (2005)
	Federal Wilderness Study Area	USGS (2005)
	Federal National Monument	USGS (2005)
	Federal National Battlefield	USGS (2005)
	Federal Recreation Area	USGS (2005)
	Federal National Conservation Area	USGS (2005)
	Federal Wildlife Refuge	USGS (2005)
	Federal Wildlife Area	USGS (2005)
	Federal Wild and Scenic Area	USGS (2005)

Table A-4. Capacity Factors for Concentrating Solar Power[a]

Class	Kwh/m2/day	Capacity Factor
1	5–6.25	0.315
2	6.25–7.25	0.393
3	7.25–7.5	0.428
4	7.5–7.75	0.434
5	> 7.75	0.448

[a] (SAM)

Table A-5. Exclusions and Constraints for Onshore Wind Power

Slope Exclusion	> 20%	
Distance Exclusion	< 3 km Distance to Excluded Area (does not apply to water)	
Land Type(s) Exclusion	50% Forest Service Lands (includes National Grasslands, excludes ridge crests)	USGS (2005)
	50% Department of Defense Lands (excludes ridge crest)	USGS (2005)
	50% GAP Land Stewardship Class 2 - Forest	CBI (2004)
	50% Exclusion of non-ridge crest forest (non-cumulative over Forest Service Land)	USGS (2005)
	Airports	ESRI (2003)
	Urban Areas	ESRI (2004)
	LULC - Wetlands	USGS (1993)
	LULC - Water	USGS (1993)
	Forest Service IRA (Inventoried Roadless Areas)	USFS (2003)
	National Park Service Lands	USGS (2005)
	Fish & Wildlife Lands	USGS (2005)
	Federal Parks	USGS (2005)
	Federal Wilderness	USGS (2005)
	Federal Wilderness Study Area	USGS (2005)
	Federal National Monument	USGS (2005)
	Federal National Battlefield	USGS (2005)
	Federal Recreation Area	USGS (2005)
	Federal National Conservation Area	USGS (2005)
	Federal Wildlife Refuge	USGS (2005)
	Federal Wildlife Area	USGS (2005)
	Federal Wild and Scenic Area	USGS (2005)
	GAP Land Stewardship Class 2 - State & Private Lands Equivalent to Federal Exclusions	CBI (2004)

Table A-6. Capacity Factor for Offshore Wind Power[a]

Depth	Class	Watts/m^2	Capacity Factor
Shallow			
0–30 meters	3	300–400	0.36
0–30 meters	4	400–500	0.39
0–30 meters	5	500–600	0.45
0–30 meters	6	600–800	0.479
0–30 meters	7	> 800	0.5
Deep			
> 30 meters	3	300–400	0.367
> 30 meters	4	400–500	0.394
> 30 meters	5	500–600	0.45
> 30 meters	6	600–800	0.479
> 30 meters	7	> 800	0.5

[a] (ReEDS)

Table A-7. Conversion of Offshore Wind Speeds at 90 Meters to Power Classes[a]

Wind Speed (meters / second)	Power Class
6.4–7.0	3
7 .0–7.5	4
7.5–8.0	5
8.0–8.8	6
> 8.8	7

[a] Marc Schwartz, NREL Wind Analyst, personal communication

Table A-8. Exclusions and Constraints for Offshore Wind Power[a]

Distance Exclusion	< 50 nautical miles from shoreline
Land Type(s) Exclusion	
Federal Exclusions	National Marine Sanctuaries
	Marine Protected Areas Inventory – 'NAL', 'NIL', 'NTL'
	Office of Habitat Conservation Habitat Protection Div. EFH – Shipping Routes, Sanctuary Protected Areas
	NOAA Jurisdictional Boundaries and Limits – Coastal National Wildlife Refuges – Pacific
	Navigational & Marine Infrastructure – Shipping Lanes, Drilling Platforms (Gulf), Pipelines (Gulf), Fairways (Gulf)
	NWIOOS – Towlane Agreement WSG 2007
	World Database on Protected Areas Annual Release 2009 Global Data set – Offshore Oil & Gas Pipelines/Drilling Platforms
Texas	Pipelines & Easements
	Audubon Sanctuaries
	Gulf Inter-coastal Waterway/Ship Channels
	National Wildlife Refuges
	Shipping Safety Fairways
	State Coastal Preserves
	Dredged Material Placement Sites
	State Tracts with Resource Management Codes
North Carolina	Significant Natural Heritage Areas
	Sea Turtle Sanctuary
	Crane Spawning Sanctuary
Great Lakes	IM ACC EPA
	IM Ship Routes
Virginia	Near-shore Coastal Parks
	Threatened & Endangered Species Waters
	Crab Sanctuary
	Security Areas
	Striped Bass Sanctuary
	State Park & State Dedicated Natural Area Preserve (w/in 1 mile of shoreline)
Rhode Island	Habitat Restoration Area

	Hazardous Material Sites Designated by the U.S. EPA and RIDEM (w/in 0.5 miles of shoreline)
	CRMCWT08 (Type = 1 or 2)
South Carolina:	Refuges
	OCRM Critical Area
New Hampshire	Conservation Focus Area
Florida	Ocean Dredged Material Disposal Sites
	Aquatic Preserve Boundaries
California	Cordell Banks Closed Areas
Massachusetts	Ferry Routes
Oregon	Oregon Islands National Wildlife Refuges USFWS 2004
	Oregon Marine Managed Areas
	Oregon Cables OFCC 2005
	Dredged Material Disposal Sites ACDE 2008
New Jersey	New Jersey Coastal Wind Turbine Siting Map – Exclusion Areas

[a] Exclusions were developed by Black & Veatch (2009).

Table A-9. Exclusions and Constraints for Enhanced Geothermal Systems[a]

Land Type(s) Exclusion	National Park Service Lands
	Fish and Wildlife Service Lands
	Federal Parks
	Federal Wilderness
	Federal National Monuments
	Federal National Battlefields
	Federal Restoration Areas
	Federal National Conservation Areas
	Federal Wildlife Refuge Areas
	Federal Wild and Scenic Areas

a USGS (2005)

Table A-10. Power Densities for Enhanced Geothermal Systems[a]

Temperature C	MW / km^2
150–200	0.59
200–250	0.76
250–300	0.86
300–350	0.97
> 350	1.19

[a] Augustine (2011)

Table A-11. Exclusions and Constraints for Enhanced Geothermal Systems[a]

Depth Constraints	Depth > 3 and < 10 km
Land Type(s) Exclusion	National Park Service Lands
	Fish and Wildlife Service Lands
	Federal Parks
	Federal Wilderness
	Federal National Monuments
	Federal National Battlefields
	Federal Restoration Areas
	Federal Conservation Areas
	Federal Wildlife Refuge Areas
	Federal Wild and Scenic Areas

[a] USGS (2005)

Appendix B. Energy Consumption by State

Electric retail sales in the United States were roughly 3,754 TWh in 2010 (EIA).

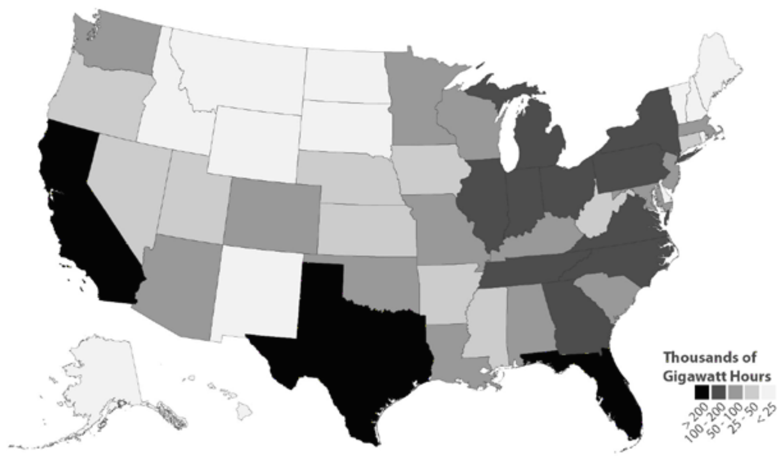

Figure B-1. Electric retail sales in the United States in 2010 (EIA).

Table B-1. Electric Retail Sales by State, 2010[a]

State	GWh	State	GWh
Alabama	90,863	Montana	13,423
Alaska	6,247	Nebraska	29,849
Arizona	72,832	Nevada	33,773
Arkansas	48,194	New Hampshire	10,890
California	258,525	New Jersey	79,179
Colorado	52,918	New Mexico	22,428
Connecticut	30,392	New York	144,624
Delaware	11,606	North Carolina	136,415
District of Columbia	11,877	North Dakota	12,956
Florida	231,210	Ohio	154,145
Georgia	140,672	Oklahoma	57,846
Hawaii	10,017	Oregon	46,026
Idaho	22,798	Pennsylvania	148,964
Illinois	144,761	Rhode Island	7,799
Indiana	105,994	South Carolina	82,479
Iowa	45,445	South Dakota	11,356
Kansas	40,421	Tennessee	103,522
Kentucky	93,569	Texas	358,458
Louisiana	85,080	Utah	28,044
Maine	11,532	Vermont	5,595
Maryland	65,335	Virginia	113,806
Massachusetts	57,123	Washington	90,380
Michigan	103,649	West Virginia	32,032
Minnesota	67,800	Wisconsin	68,752
Mississippi	49,687	Wyoming	17,113
Missouri	86,085	**U.S. Total**	**3,754,486**

[a] EIA