U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

Renewable Energy Resource Assessment Information for the United States

March 2022

Disclaimer

Preface

This report responds to legislative language set forth in Section 201 of the Energy Policy Act of 2005 (EPAct 2005) on page 58, wherein it is stated:

> … "(a) RESOURCE ASSESSMENT.—Not later than 6 months after the date of enactment of this Act, and each year thereafter, the Secretary shall review the available assessments of renewable energy resources within the United States, including solar, wind, biomass, ocean (including tidal, wave, current, and thermal), geothermal, and hydroelectric energy resources, and undertake new assessments as necessary, taking into account changes in market conditions, available technologies, and other relevant factors.
>
> (b) CONTENTS OF REPORTS.—Not later than 1 year after the date of enactment of this Act, and each year thereafter, the Secretary shall publish a report based on the assessment under subsection (a). The report shall contain—
>
> (1) a detailed inventory describing the available amount and characteristics of the renewable energy resources; and
>
> (2) such other information as the Secretary believes would be useful in developing such renewable energy resources, including descriptions of surrounding terrain, population and load centers, near-by energy infrastructure, location of energy and water resources, and available estimates of the costs needed to develop each resource, together with an identification of any barriers to providing adequate transmission for remote sources of renewable energy resources to current and emerging markets, recommendations for removing or addressing such barriers, and ways to provide access to the grid that do not unfairly disadvantage renewable or other energy producers."

Author

The author of this report is Adria Brooks, U.S. Department of Energy (DOE EERE Strategic Analysis).

Acknowledgments

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List of Acronyms

BETO	Bioenergy Technologies Office
CONUS	conterminous United States
CSP	concentrating solar power
DOE	U.S. Department of Energy
EERE	Office of Energy Efficiency & Renewable Energy
EGS	enhanced geothermal systems
GTO	Geothermal Technologies Office
NREL	National Renewable Energy Laboratory
SETO	Solar Energy Technology Office
USGS	U.S. Geological Survey
WETO	Wind Energy Technology Office
WIND	Wind Integration National Dataset
WPTO	Water Power Technologies Office

Executive Summary

Section 201 of the Energy Policy Act of 2005 directs the U.S. Department of Energy (DOE) to prepare a report presenting an inventory of U.S. renewable resource assessments for solar, wind, biomass, ocean, hydropower, and geothermal energy resource technologies (42 U.S.C. 15851[b]). This report summarizes both the gross resource and the technical potential of these renewable energy resources for producing electricity from nearly 30 national laboratory studies published since 2012. Increased attention is given to the renewable energy resources available near federally recognized Tribal nations and low-to-moderate income households, where assessed. This report is limited to technically recoverable assessments and does not include analyses of cost and barriers.

The United States is a resource-rich country, with abundant renewable energy resources. There is great geographic spread among the gross resources: every region of the country has access to multiple renewable energy resources. In general terms, solar energy is most abundant at mid and low latitudes, wind energy dominates on the Central Plains and the coastal shores, biomass and hydropower are both found in the Pacific Northwest and eastern half of the United States, ocean energy is highest along the Pacific Coast, and geothermal resources are greatest in the Western states. Figure ES-1 (page iv) shows the location of major geothermal, solar, and wind energy resources and the locations of existing hydropower resources. This map does not show the locations of all renewable energy resources that could be accessed with emerging technologies.

The United States has a large, untapped technical potential to convert gross resources into electricity. Recent technological advances allow numerous ways to convert resources into electricity. This report considers 11 technology categories to convert renewable energy into electricity. The technical potential and historical energy production of each technological category is shown in Table ES-1 (page v) and Figure ES-2 (page vi). In total, an estimated 463,400 terawatt-hours (TWh) of renewable energy technical potential are available to the United States annually—this is more than 100 times the 4,000 TWh of electricity consumed in 2020. Of this total technical potential, at least 9% is found within 10 miles (mi) of federally recognized Tribal lands. Currently, deployed renewable energy technologies make up only 0.2% of the total resource potential available to the United States.

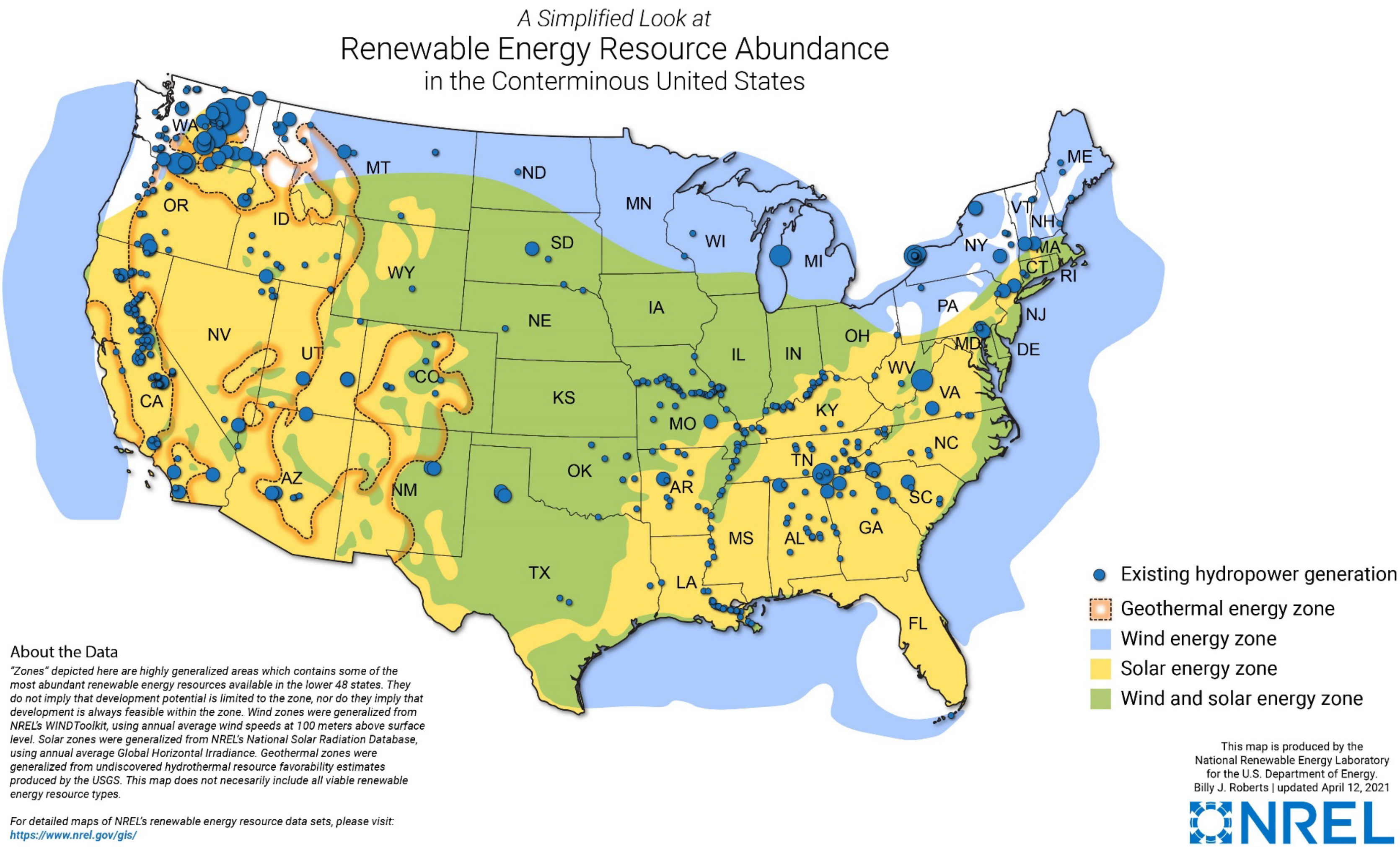

Image is from the National Renewable Energy Laboratory.

Table ES-1. Annual Technical Energy Potential for All Renewable Energy Resources in the United States, the Portion of Each Available within 10 mi of Federally Recognized Tribal Lands, and Historical 2020 Energy Production

Resource	Potential Capacity in the U.S. (GW)	Potential Energy Production in the United States (TWh/yr)	Potential Energy Production near Tribal Lands (TWh/yr) [a]	2020 Energy Production in the United States (TWh/yr) [b]
Solar - Utility Scale PV [c, d]	157,765	297,486	22,736	88
Solar – CSP [e]	16,691	87,728	14,703	3
Wind - Land Based [f]	9,124	24,774	4,940	338
Geothermal – Enhanced [g]	3,377	24,638	[not assessed]	0
Wind – Offshore [h, i]	5,075	19,290	[not assessed]	0
Wind – Distributed [j]	3,000	4,400	[not assessed]	2 [j]
Water – Ocean [k]	[not assessed]	2,300	[not assessed]	0
Solar - Distributed PV [l]	1,118	1,432	416*[l]	42
Water – Hydropower [d, m, n]	156	661	225	291
Biomass [c, d]	71	505	20†	56
Geothermal – Hydrothermal [g]	24	181	4	17

* Annual energy available to low-to-moderate income residential households in the United States, regardless of Tribal affiliation
† Combined woody solid and distributed biogas from source (a)
All referenced data rounded to nearest GW or TWh/yr.

[a] (Milbrandt, Heimiller, & Schwabe, Techno-Economic Renewable Energy Potential on Tribal Lands, 2018)
[b] (U.S. Energy Information Administration, 2021) (preliminary data)
[c] (Brown, et al., 2016)
[d] (U.S. Department of Energy Office of Energy Efficiency and Renewable Energy, 2014)
[e] (Murphy, et al., 2019)
[f] (Lopez, et al., 2021)
[g] (Augustine, Ho, & Blair, 2019)
[h] (Musial, Heimiller, Beiter, Scott, & Draxl, 2016)
[i] (Doubrawa, et al., 2017)
[j] (Lantz, Sigrin, Gleason, Preus, & Baring-Gould, 2016)
[k] (Kilcher, Fogarty, & Lawson, 2021)
[l] (Gagnon, Margolis, Melius, Phillips, & Elmore, 2016)
[m] (Hadjerioua, Wei, & Kao, 2012)
[n] (McManamay, et al., 2014)

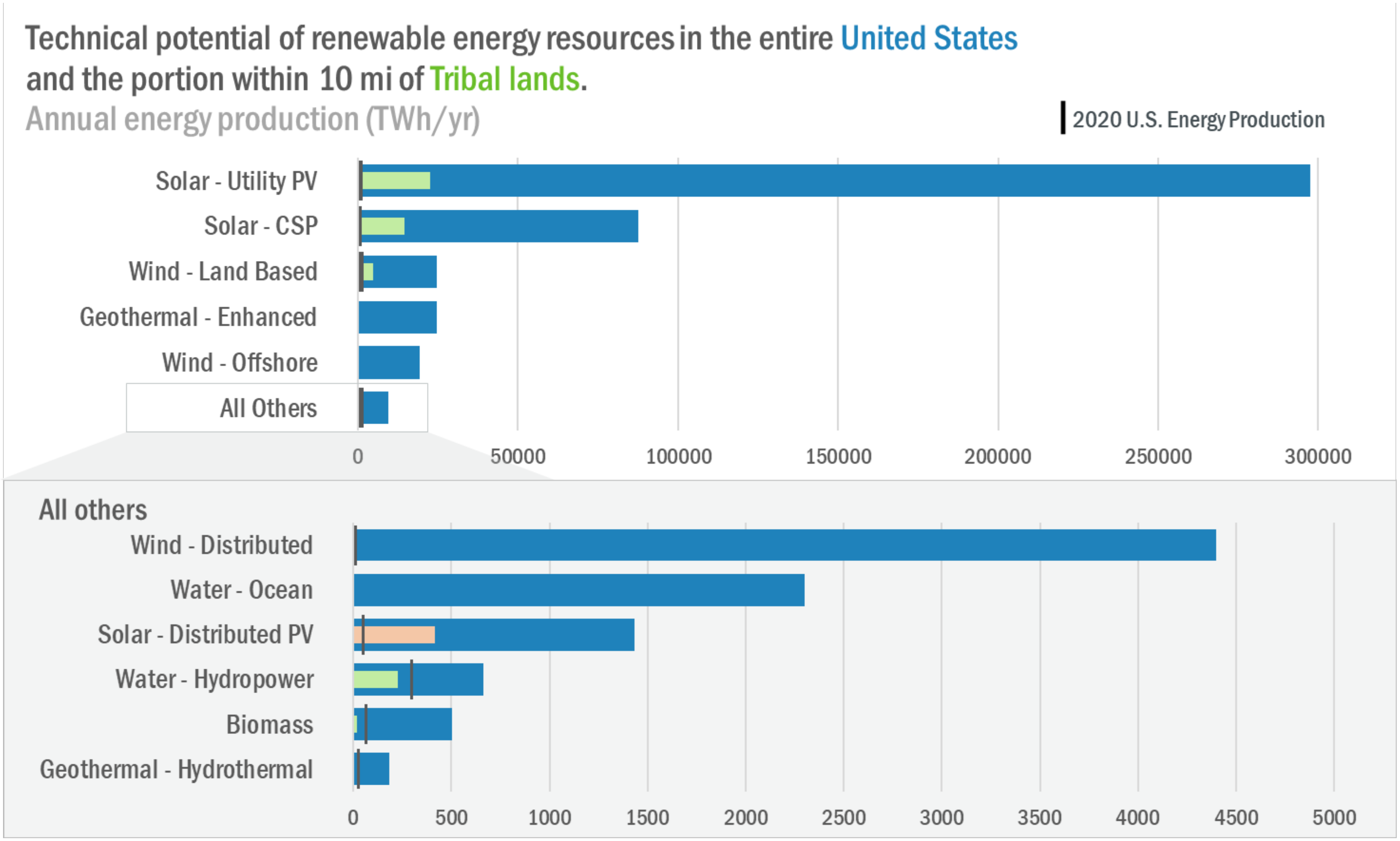

Figure ES-2. Annual technical energy potential for all renewable energy resources in the United States (blue outer bar), the portion of each available within 10 mi of federally recognized Tribal lands (green inner bar), and historical 2020 energy production (black vertical line).

References to all studies provided in Table ES-1.
Orange inner bar for Solar - Distributed PV is technical potential for all low-to-moderate income households, regardless of Tribal affiliation. 2020 energy production data is preliminary.

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1 Introduction

This report includes an inventory of national laboratory-updated resource assessment studies for the renewable energy resources in the United States as outlined above (i.e., solar, wind, biomass, ocean, geothermal, and hydroelectric). The content of the report summarizes the findings of resource assessment studies and highlights research areas to improve resource data and changes as necessitated by evolving technologies.

1.1 Potential Assessment

The potential of a renewable energy resource for producing electricity can be measured in several ways. Figure 1 illustrates key differences between gross resource, technical, economic and market potentials (Brown, et al., 2016). *Gross resource potential* is the amount of energy physically available to a region (Brown, et al., 2016). The gross resource potential for wind energy, for example, is the average wind speed at different times of year at the exact height of the turbine used to convert wind to electricity. *Technical potential* represents the achievable energy capacity and generation of a particular technology given the gross resource potential, system performance, topographic limitations, environmental constraints, and land use constraints (Cox, Lopez, Watson, Grue, & Jennifer, 2018). This report presents both the gross resource and technical potential for different renewable energy technologies across the United States.

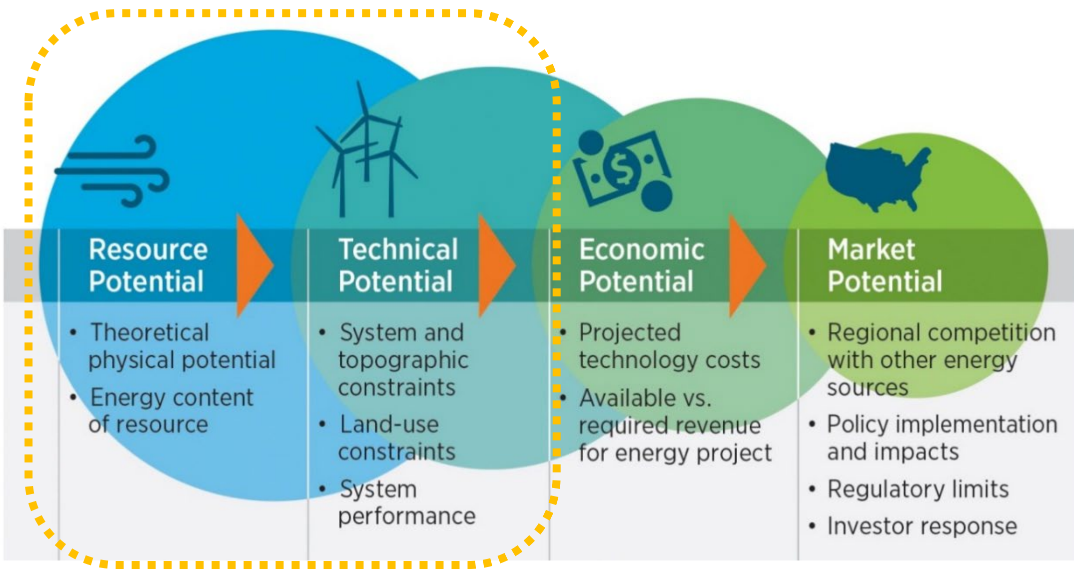

Figure 1. Differences in four common potential assessment calculations

Image is from (Brown, et al., 2016). Gross resource and technical potential are within the purview of this report (indicated by box).

This report quantifies technical potentials for renewable energy technologies, including solar, wind, biomass, ocean, geothermal, and hydropower energy technologies. Other "clean" energy sources—such as storage, energy efficiency, and nuclear energy—are not considered here. Furthermore, the report quantifies only the potential of renewable energy technologies to produce electricity; it does not quantify other end-use commodities, such as hydrogen, direct heating, biofuels, or industrial chemicals. Ongoing U.S. Department of Energy (DOE) research is assessing the technical potential of renewable resources to produce nonelectric end-use commodities.

1.2 Published Potential Assessments

Technological advances allow numerous ways to convert gross resources into electricity. These gross resources are diverse enough that each requires different technological solutions to extract their power. Solar power, for example, can be converted to electricity using either solar photovoltaic (PV) panels or a large array of mirrors to direct sunlight at a point to be heated. Because of the diversity of options available to convert gross resources into electricity, this report addressees several energy technologies individually. Table 1 lists the major energy conversion methods considered in this report by the DOE Office of Energy Efficiency and Renewable Energy technology office that is responsible for research in each resource area.

Table 1. Technical Energy Conversion Methods for Each of the Renewable Energy Resources, Organized by DOE Office

Solar Energy Technologies Office	Wind Energy Tech. Office	Bioenergy Tech. Office	Water Power Tech. Office	Geothermal Tech. Office
• Utility-scale PV • Distributed PV • Concentrating solar-thermal power	• Land-based wind • Offshore wind • Distributed wind	• Biopower	• Ocean • Hydropower	• Hydrothermal • Enhanced geothermal systems

Ocean and hydropower energy are discussed independently in this report to align with congressional EPAct 2005 language.

The national laboratories maintain regularly updated databases for national renewable resource assessments and conduct periodic technical potential assessment studies. Three major studies conducted in the last decade by the National Renewable Energy Laboratory (NREL) assessed the technical potential of renewable energy resources:

- U.S. Renewable Energy Technical Potentials: A GIS-Based Analysis (Lopez, et al., 2012)
- Estimating Renewable Energy Economic Potential in the United States: Methodology and Initial Results (Brown, et al., 2016)
- Techno-Economic Renewable Energy Potential on Tribal Lands (Milbrandt, et al., 2018).

These three studies compared the technical potential for most of the renewable energy resources highlighted in EPAct 2005 for every U.S. state. Other resources assessment studies of individual technologies were performed as needed to reflect updated datasets, technology evolution, and methodologies. Differences in technical potential findings between all studies represent differences in study assumptions and the technological improvements that occurred between study years. All national laboratory studies used in this report are listed in Table 2 (page4).

The findings of the most recent study for each resource and technology type are shown in Table 3 (page vii) and Figure 2 (page viii). The most recent technical potential reports estimate that nearly 463,400 terawatt-hours (TWh) of annual energy is available in the United States across all technology groups (calculated as the sum of potential energy production for all technologies in Table 3). Of this potential, over 9% is found within 10 mi of federally recognized Tribal lands. In 2020, the total electricity production in the United States was nearly 4,000 TWh, and more than 800 TWh was produced by renewable energy resources (U.S. Energy Information Administration, 2021) (preliminary data).

1.3 Report Overview

The subsequent sections of the report are outlined by energy resource: solar, wind, biomass, ocean, geothermal, and hydropower. The assessment of the gross resource and the technical potential of converting that resource into electricity are given in each section. Multiple technologies can convert each renewable resource into electricity, and some have much greater potential than others, given the characteristics of each technology. Where the potential between technology categories vary greatly, it is noted in each resource section. This report does not include analysis of cost and barriers, but is limited to a technically recoverable assessment and not a report of economic assessments.

Table 2. DOE Potential Assessments Used in this Report, Organized by Energy Resource

Resource	Potential	Technology	Scope	Source	Important Notes
Solar	Gross Resource	N/A	Entire United States	(National Renewable Energy Laboratory, 2020)	Considers solar irradiance at many angles
	Technical	Utility PV, distributed PV, concentrating solar power (CSP)	Entire United States	(Lopez, Roberts, Heimiller, Blair, & Porro, 2012)	
		Utility PV, distributed PV	Conterminous United States (CONUS)	(Brown, et al., 2016)	Updates Lopez, et al., 2012 assumptions
		Distributed PV	CONUS	(Gagnon, Margolis, Melius, Phillips, & Elmore, 2016)	Uses lidar to make rooftop area estimates
		PV (utility and distributed grouped), CSP	CONUS and Alaska	(Milbrandt, Heimiller, & Schwabe, 2018)	Potential on Tribal lands; uses Lopez, et al., 2012 assumptions
		Distributed PV	Entire United States	(Sigrin & Mooney, 2018)	Potential specific to low-to-moderate income housing; uses Gagnon, et al., 2016 assumptions
		CSP	CONUS	(Murphy, et al., 2019)	
Wind	Gross Resource	Land-based, offshore	Entire United States	(Draxl, Hodge, Clifton, & McCaa, 2015)	
	Technical	Land-based, offshore	Entire United States	(Lopez, Roberts, Heimiller, Blair, & Porro, 2012)	
		Land-based	CONUS	(Brown, et al., 2016)	Updates Lopez, et al., 2012 assumptions
		Distributed	Continental United States	(Lantz, Sigrin, Gleason, Preus, & Baring-Gould, 2016)	Addressable resource (less restrictive land use than technical potential)

Resource	Potential	Technology	Scope	Source	Important Notes
		Offshore	CONUS and Hawaii	(Musial, Heimiller, Beiter, Scott, & Draxl, 2016)	
		Offshore	Alaska	(Doubrawa, et al., 2017)	Companion to Musial, et al., 2016 for Alaska; considered out to U.S. exclusive economic zone with sea depths < 1 km and < 90% sea ice cover
		Land-based	CONUS and Alaska	(Milbrandt, Heimiller, & Schwabe, 2018)	Potential on Tribal lands; uses Lopez, et al., 2012 assumptions
		Land-based	CONUS	(Lopez, et al., 2021)	Uses 2018 turbine characteristics, state citing regulations, high-resolution spatial dataset
Biomass	Gross Resource	Methane	Entire United States	(Saur & Milbrandt, 2014)	Assessment conducted as part of renewable hydrogen study; methane from waste streams and livestock
		Methane	CONUS	(Milbrandt, Bush, & Melaina, 2016)	Assessment conducted as part of renewable hydrogen study; methane from waste streams and livestock
	Technical	Solid, methane	Entire United States	(Lopez, Roberts, Heimiller, Blair, & Porro, 2012)	
		Solid	CONUS	(Brown, et al., 2016)	Updates Lopez, et al., 2012 assumptions
		Solid	CONUS and Alaska	(Milbrandt, Heimiller, & Schwabe, 2018)	Potential on Tribal lands; uses Lopez, et al., 2012 assumptions
Hydropower	Technical Potential	Powering non-powered dams	CONUS	(Hadjerioua, Wei, & Kao, 2012)	
		New stream-reach development	Entire United States	(McManamay, et al., 2014)	

Resource	Potential	Technology	Scope	Source	Important Notes
		Non-powered dams and new stream-reach development	CONUS and Alaska	(Milbrandt, Heimiller, & Schwabe, 2018)	Potential on Tribal lands; uses Lopez, et al., 2012 assumptions
Ocean	Gross Resource and Technical	Ocean wave	Entire United States	(Electric Power Rearch Institute, 2011)	Sea depths of 50 m and 200 m
		Ocean wave	Entire United States	(Previsic, et al., 2012)	Sea depth of 100 m
		Ocean wave, tidal current, ocean current, ocean thermal, river current	Entire United States	(Kilcher, Fogarty, & Lawson, 2021)	Within U.S. exclusive economic zone
Geothermal	Gross Resource	Hydrothermal and enhanced geothermal systems (EGS)	Entire United States	(Williams, Reed, Mariner, DeAngelo, & Galanis, 2008)	U.S. Geological Survey (USGS) study
	Gross Resource and Technical	Hydrothermal and EGS	CONUS	(Augustine, Ho, & Blair, 2019)	Updates Williams, et al., 2008 assumptions
	Technical		Entire United States	(Lopez, Roberts, Heimiller, Blair, & Porro, 2012)	Excludes Alaska and Hawaii for EGS
		Hydrothermal	CONUS and Alaska	(Milbrandt, Heimiller, & Schwabe, 2018)	Potential on Tribal lands; uses Lopez, et al., 2012 assumptions

Table 3. Annual Technical Energy Potential for All Renewable Energy Resources in the United States, the Portion of Each Available within 10 mi of Federally Recognized Tribal Lands, and Historical 2020 Energy Production

Resource	Potential Capacity in the U.S. (GW)	Potential Energy Production in the United States (TWh/yr)	Potential Energy Production near Tribal Lands (TWh/yr) [a]	2020 Energy Production in the United States (TWh/yr) [b]
Solar - Utility Scale PV [c, d]	157,765	297,486	22,736	88
Solar – CSP [e]	16,691	87,728	14,703	3
Wind - Land Based [f]	9,124	24,774	4,940	338
Geothermal – Enhanced [g]	3,377	24,638	[not assessed]	0
Wind – Offshore [h, i]	5,075	19,290	[not assessed]	0
Wind – Distributed [j]	3,000	4,400	[not assessed]	2 [j]
Water – Ocean [k]	[not assessed]	2,300	[not assessed]	0
Solar - Distributed PV [l]	1,118	1,432	416*[l]	42
Water – Hydropower [d, m, n]	156	661	225	291
Biomass [c, d]	71	505	20†	56
Geothermal – Hydrothermal [g]	24	181	4	17

* Annual energy available to low-to-moderate income residential households in the United States, regardless of Tribal affiliation

† Combined woody solid and distributed biogas from source (a)

All referenced data rounded to nearest GW or TWh/yr.

[a] (Milbrandt, Heimiller, & Schwabe, Techno-Economic Renewable Energy Potential on Tribal Lands, 2018)
[b] (U.S. Energy Information Administration, 2021) (preliminary data)
[c] (Brown, et al., 2016)
[d] (U.S. Department of Energy Office of Energy Efficiency and Renewable Energy, 2014)
[e] (Murphy, et al., 2019)
[f] (Lopez, et al., 2021)
[g] (Augustine, Ho, & Blair, 2019)
[h] (Musial, Heimiller, Beiter, Scott, & Draxl, 2016)
[i] (Doubrawa, et al., 2017)
[j] (Lantz, Sigrin, Gleason, Preus, & Baring-Gould, 2016)
[k] (Kilcher, Fogarty, & Lawson, 2021)
[l] (Gagnon, Margolis, Melius, Phillips, & Elmore, 2016)
[m] (Hadjerioua, Wei, & Kao, 2012)
[n] (McManamay, et al., 2014)

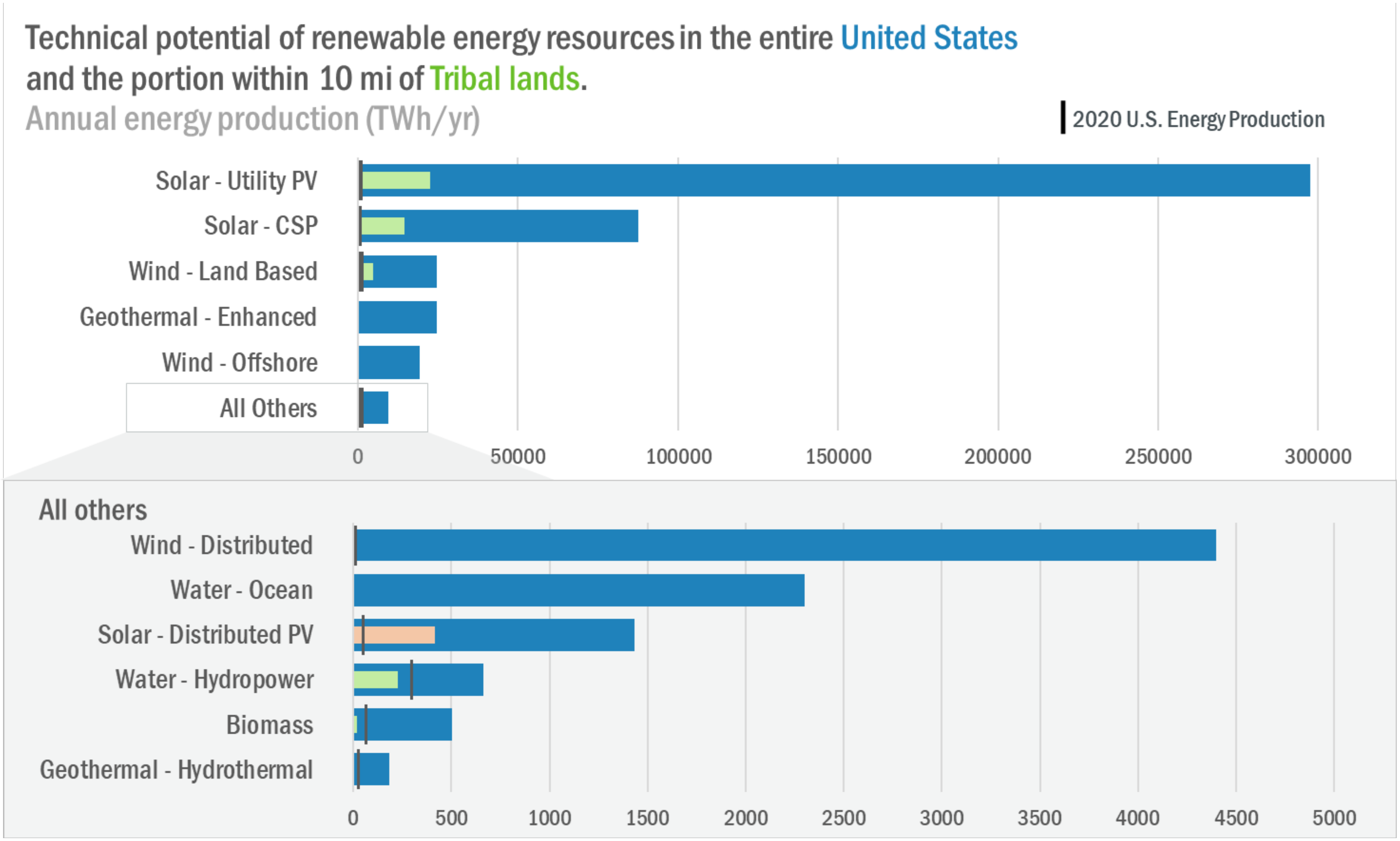

Figure 2. Annual technical energy potential for all renewable energy resources in the United States, the portion of each available within 10 mi of federally recognized Tribal lands, and historical 2020 energy production.

References to all studies provided in Table 3.
Orange inner bar for Solar - Distributed PV is technical potential for all low-to-moderate income households, regardless of Tribal affiliation. 2020 energy production data is preliminary.

2 Solar Energy

2.1 Summary of Solar Energy Potential

Of all renewable energy resources, solar energy has the largest potential for electricity production in the United States. Three solar energy technologies are considered in this report: utility-scale PV, distributed PV, and concentrating solar-thermal power (CSP). Studies of resource potential estimate there is 297,486 TWh of annual electricity technical potential from utility-scale PV (Brown, et al., 2016) and 87,728 TWh from concentrating solar power (CSP) technologies.[1] Distributed PV on building rooftops has a technical potential of 1,432 TWh (Gagnon, Margolis, Melius, Phillips, & Elmore, 2016). Table 4 shows the technical potential of all solar energy resources considered in the report, including the national capacity and energy production and the energy production within 10 miles of federally recognized Tribal lands. Figure 3 compares the annual energy production technical potential and 2020 energy production.

Table 4. Technical Potential and Historical Generation of Solar Energy Resources

Resource	Potential Capacity in U.S. (GW)	Potential Energy Production in U.S. (TWh/yr)	Potential Energy Production near Tribal Lands (TWh/yr)	2020 Energy Production in United States (TWh/yr)
Solar: Utility-Scale PV	157,765	297,486	22,736	88
Solar: CSP	16,691	87,728	14,703	3
Solar: Distributed PV	1,118	1,432	416*	42

U.S. capacity and energy production potential are from (U.S. Department of Energy Office of Energy Efficiency and Renewable Energy, 2014) (Brown, et al., 2016) (Gagnon, Margolis, Melius, Phillips, & Elmore, 2016) (Murphy, et al., 2019). Energy potential that could be produced within 10 mi of federally recognized Tribal lands of utility-scale PV and CSP is from (Milbrandt, Heimiller, & Schwabe, 2018). The asterisk (*) indicates distributed PV that is available to low-to-moderate income households, regardless of Tribal affiliation (Sigrin & Mooney, 2018). 2020 energy production is preliminary data (U.S. Energy Information Administration, 2021).

[1] Values were calculated from technical potential in (Murphy, et al., 2019), assuming a capacity factor of 60% from increased technological advances.

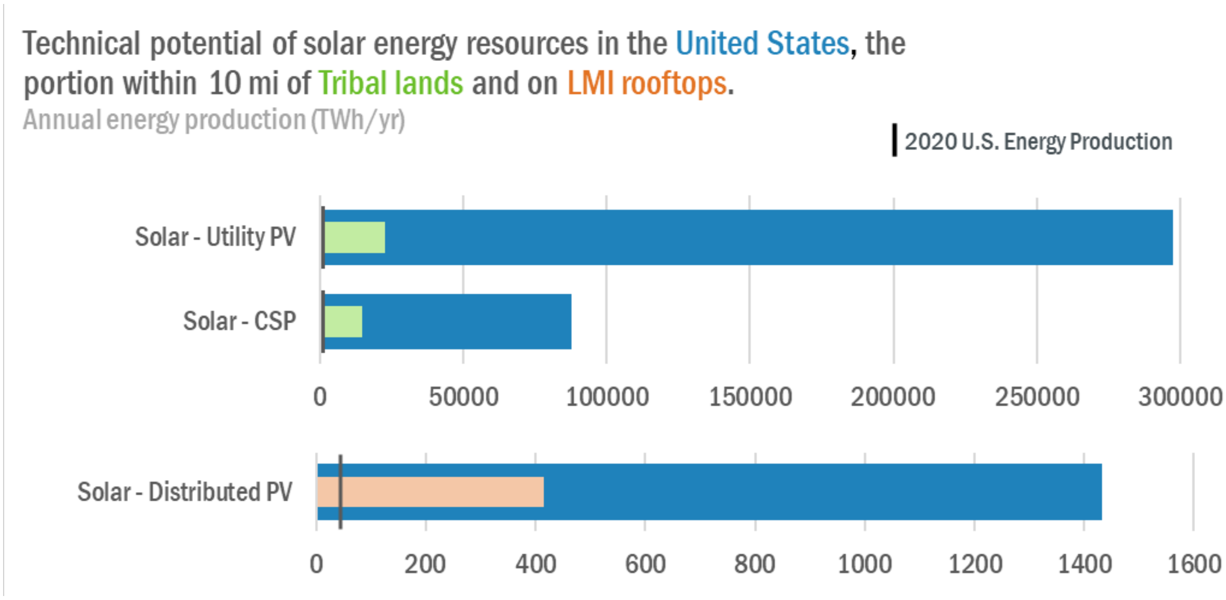

Figure 3. National energy production for solar energy resources

U.S. technical potential (outer bar) is from (Brown, et al., 2016), (Gagnon, Margolis, Melius, Phillips, & Elmore, 2016), and (Murphy, et al., 2019); technical potential within 10 mi of federally recognized Tribal lands (inner bar) is from (Milbrandt, Heimiller, & Schwabe, 2018); and 2020 energy production (line) is preliminary data from (U.S. Energy Information Administration, 2021). Inner bar of distributed PV shows available to low-to-moderate income households, regardless of Tribal affiliation (Sigrin & Mooney, 2018).

2.2 Introduction

Amounts of solar radiation for energy conversion are affected by predictable factors such as the site location (e.g., latitude, longitude, and elevation), time of day, month, season, or year. Less predictable factors include variations in cloud cover and the locations of clouds in the sky. Collectively, these factors contribute to strong diurnal, monthly, seasonal, and interannual patterns in the amount of solar energy available at Earth's surface. The resulting temporal variability of the solar resource at a single location can be expected over a wide range of timescales (i.e., minutes to decades). The spatial variability of solar resource is fairly low for distances less than 100 km. Interactions of solar energy with the atmosphere and Earth's surface also produce three types of basic solar resources: direct normal (beam), diffuse (sky), and global (total) irradiance, all of which can be used to produce electricity (U.S. Department of Energy, 2013).

Three solar energy technologies are included in this report: utility-scale photovoltaics, distributed photovoltaics, and concentrating solar-thermal power. Photovoltaic (PV) technology converts solar energy directly into electricity. Utility-scale PV projects are large projects that sell their power directly to utilities. Distributed PV systems are installed at or near where the electricity is used, as opposed to central systems that supply electricity to grids. Distributed PV systems are commonly, but not exclusively, installed on building rooftops.[2] Concentrating solar-thermal power (CSP) "uses mirrors or lenses to generate high-temperature thermal energy from concentrated sunlight. This energy can be used, in turn, to drive turbines, producing electricity in a manner similar to that used in conventional thermal power plants." (Murphy, et al., 2019)

2.3 Potential Assessment

2.3.1 Resource Potential

NREL has maintained the National Solar Radiation Database for over 25 years. It reflects measured data and empirical modeling to provide solar radiation data for the entire United States (National Renewable Energy Laboratory, 2020). Figure 4 presents the annual average solar radiation across the United States (Sengupta, et al., 2018). Solar radiation will be greater during the summer and lower during the winter.

[2] The resource potential studies reported here consider rooftop distributed PV systems.

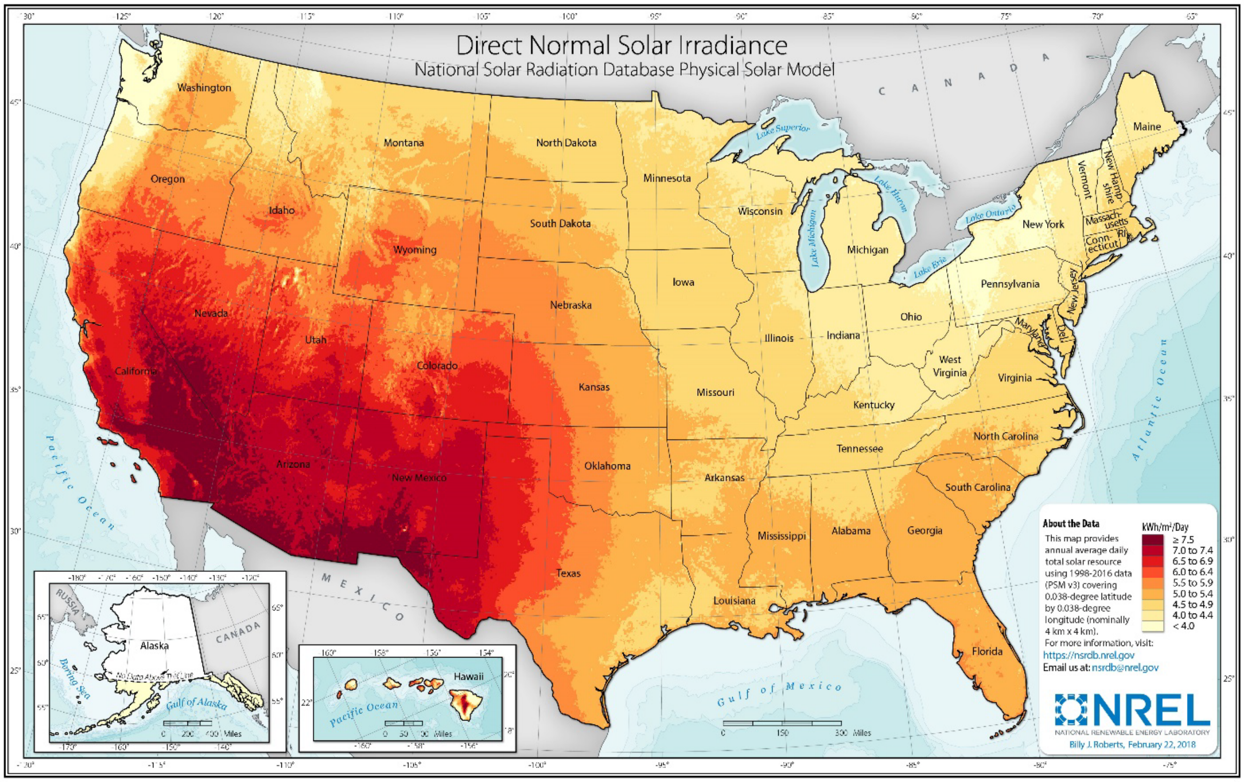

Figure 4. Average annual solar resource for the United States

Image is from (Sengupta, et al., 2018).

2.3.2 Technical Potential

2.3.2.1 Utility-Scale PV

Utility-scale PV technology has by far the largest technical potential of any renewable energy resource in the United States. There is an estimated total technical potential of 157.8 terawatts (TW) of capacity and 297,475 terawatt-hours (TWh) of utility PV energy production in the United States (Brown, et al., 2016). By comparison, the total U.S. electricity generation fleet produced just over 4,000 TWh of energy in 2020 (U.S. Energy Information Administration, 2021) (preliminary data).

Technical potential estimates exclude environmentally sensitive areas (e.g., federally protected wetlands and forests), land with slopes greater than 5° (slightly steeper than wheelchair ramps that are compliant with the Americans with Disabilities Act), and land far away from road infrastructure (Lopez, Roberts, Heimiller, Blair, & Porro, 2012) (Brown, et al., 2016). The technical potential in each individual state is shown in Figure 5. Roughly 7.6% of the total utility PV potential is located within 10 miles of recognized Tribal land[3] .

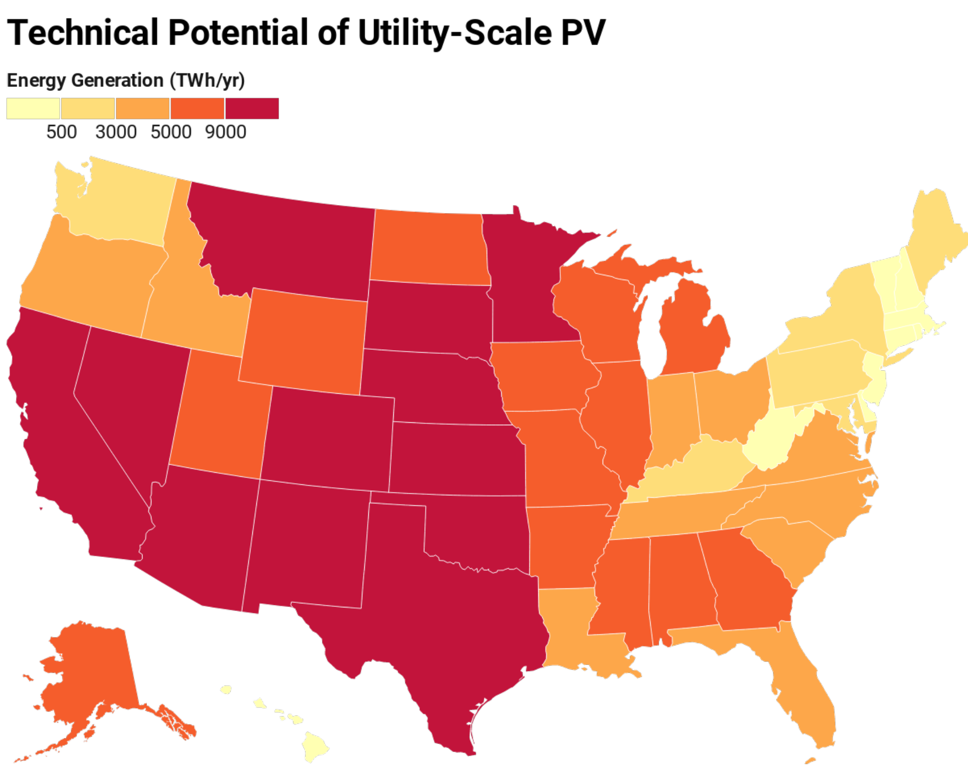

Figure 5. Annual energy production technical potential for utility-scale PV

Contiguous U.S. data are from (Brown, et al., 2016). Alaska and Hawaii data are from (Lopez, Roberts, Heimiller, Blair, & Porro, 2012).

[3] Calculated using the values and relevant references in Table 4.

2.3.2.2 Distributed PV

Studies reporting distributed PV potential have stricter land exclusions than utility PV and are assumed to only be installed on building rooftops. Thus, distributed PV has only a fraction of the potential of utility PV. There is an estimated technical potential capacity of 1.1 TW and annual energy production of 1,432 TWh for distributed PV on all building rooftops in the United States (Gagnon, Margolis, Melius, Phillips, & Elmore, 2016). A map of potential annual energy production for all states is given in Figure 6.

Of all rooftop solar PV technical potential, 70% is located on residential buildings and 29% of which is located on low-to-moderate income residential buildings[4] (Sigrin & Mooney, 2018). A significant proportion of low-to-moderate income household electrical consumption could be offset by rooftop PV if solar panels were installed on these homes (Sigrin & Mooney, 2018). Figure 7 (page 15) shows the percentage of low-to-moderate income household electricity consumption can be offset, on average, using distributed solar PV by U.S. County.

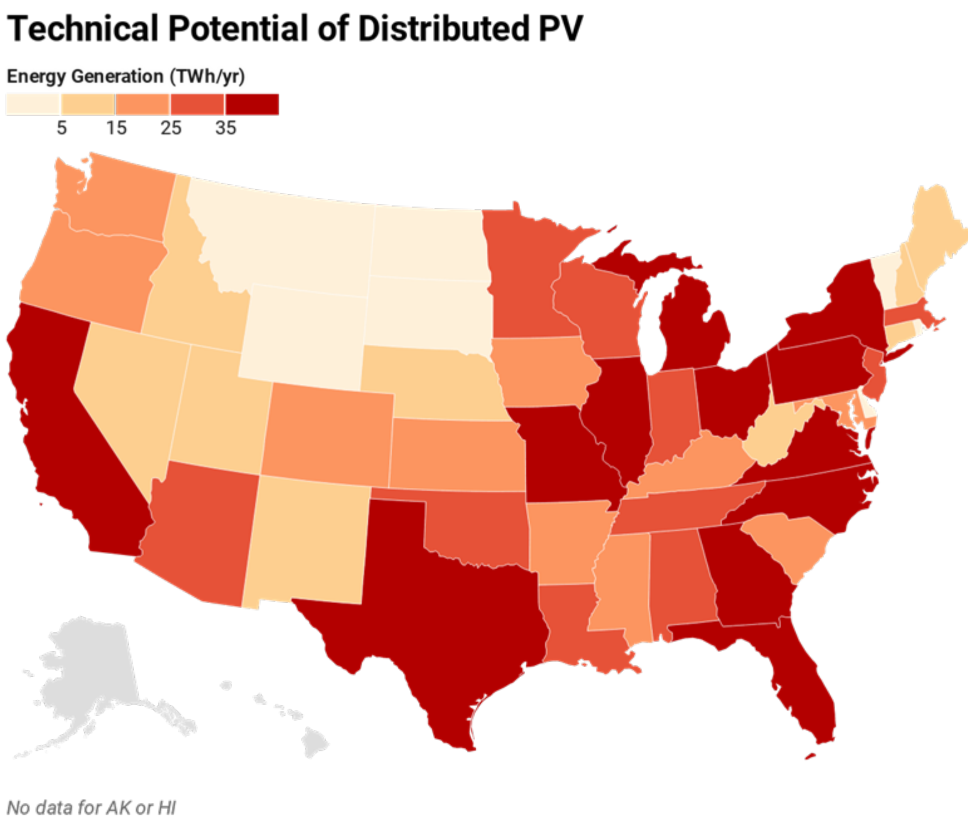

Figure 6. Annual energy production technical potential for distributed PV

Data are from (Gagnon, et al., 2016). Potential for Alaska and Hawaii were not estimated.

[4] Calculated by comparing distributed PV values from (Sigrin & Mooney, 2018) with the values and relevant references in Table 4.

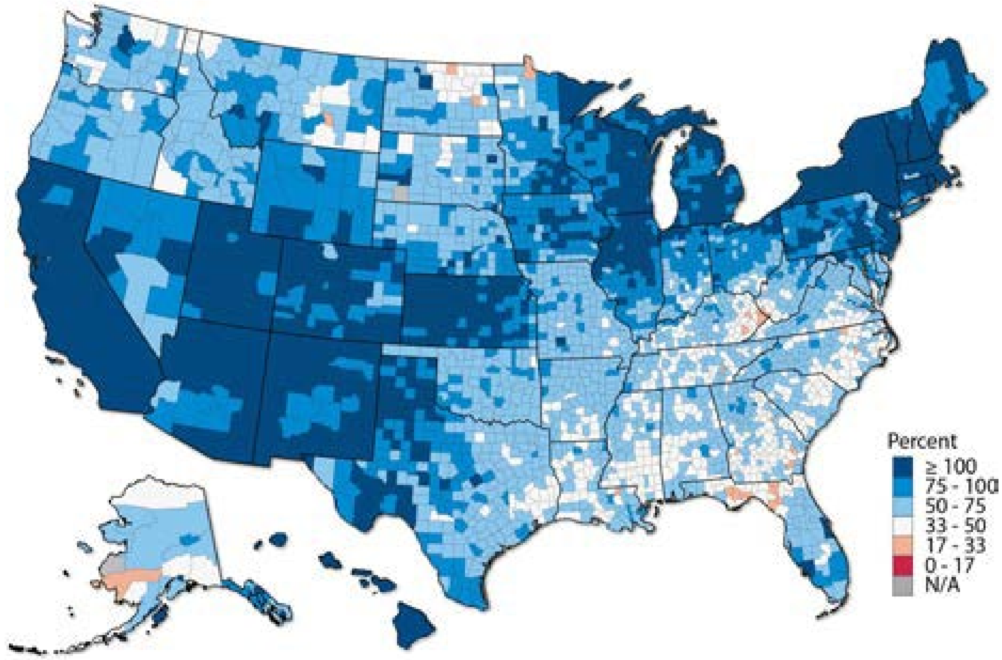

Figure 7. Percentage of low-to-moderate income household electrical consumption that can be offset by rooftop solar generation considering all low-to-moderate income residential building stock

Image is from (Sigrin & Mooney, 2018).

Concentrating Solar-Thermal Power (CSP)

Concentrating solar-thermal power plants have more siting restrictions than PV power plants. These plants require a very high-quality solar resource. For this reason, existing CSP plants have been installed mainly in the Southwest, where the solar resource is strongest year-round. As CSP technology continues to improve, there will be the potential to use lower-quality resources in the Mountain West and Southeast, but these technology advancements are not reflected in the data shown here. Additionally, CSP plants need at least 5 km^2 of uninterrupted land and must be located at least 3 km from urban centers and airports to comply with Federal Aviation Administration restrictions (Murphy, et al., 2019).

In 2012, the technical potential of CSP was calculated to be a capacity of 38 TW and an annual energy production of 116,146 TWh (Lopez, Roberts, Heimiller, Blair, & Porro, 2012). A 2019 study (Murphy, et al., 2019) updated the 2012 technical potential study to include stricter land and technology assumptions. The 2019 study estimated the technical capacity potential to be 16.7 TW, which is less than half that calculated in the 2012 study. State-level estimates from the 2019 study are shown in Figure 8. Of the total national potential for CSP energy production, 16.8% is found within 10 miles of federally recognized Tribal lands[5].

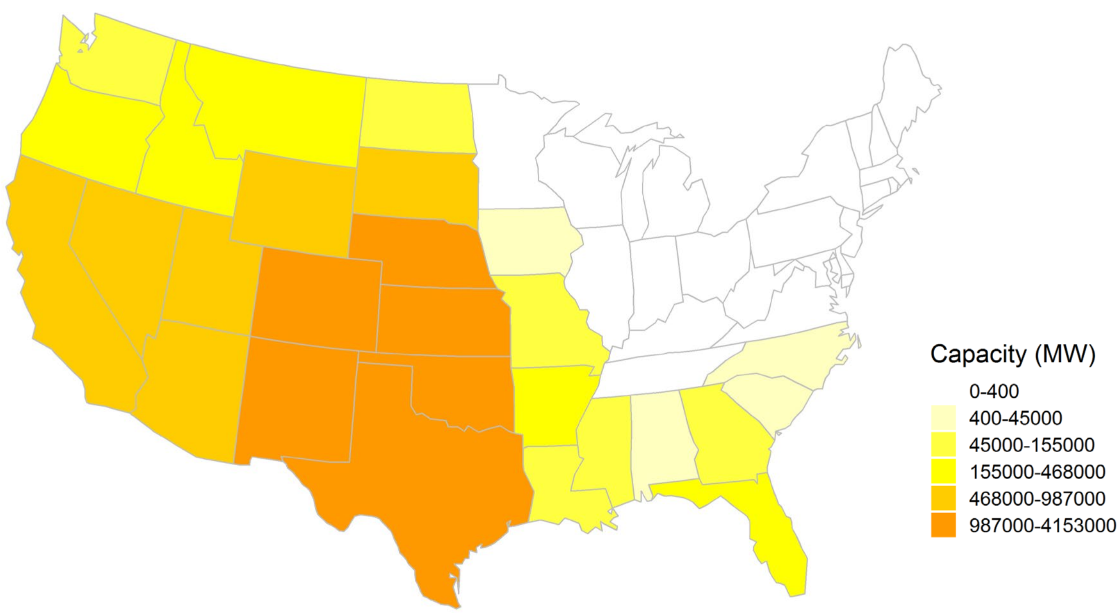

Figure 8. Technical capacity potential for concentrating solar-thermal power

Data are from (Murphy, et al., 2019).

[5] Calculated using the values and relevant references in Table 4.

2.3.3 Installed Capacity

PV technologies represent a fast-growing industry. In 2020, utility PV systems contributed 87.7 TWh to the national energy mix (U.S. Energy Information Administration, 2021), up from 0.4 TWh in 2010 (U.S. Energy Information Administration, 2021). In 2020, the combined utility and distributed PV annual energy production was 129.5 TWh and CSP plants generated 3.1 TWh (U.S. Energy Information Administration, 2021).

Cumulative utility PV installations at the end of 2019 are shown by state in Figure 9. California has the most installed utility PV. How much utility PV contributed to each state's electricity generation is shown in Figure 10. California, Nevada, and Hawaii have the highest penetration of solar PV generation.

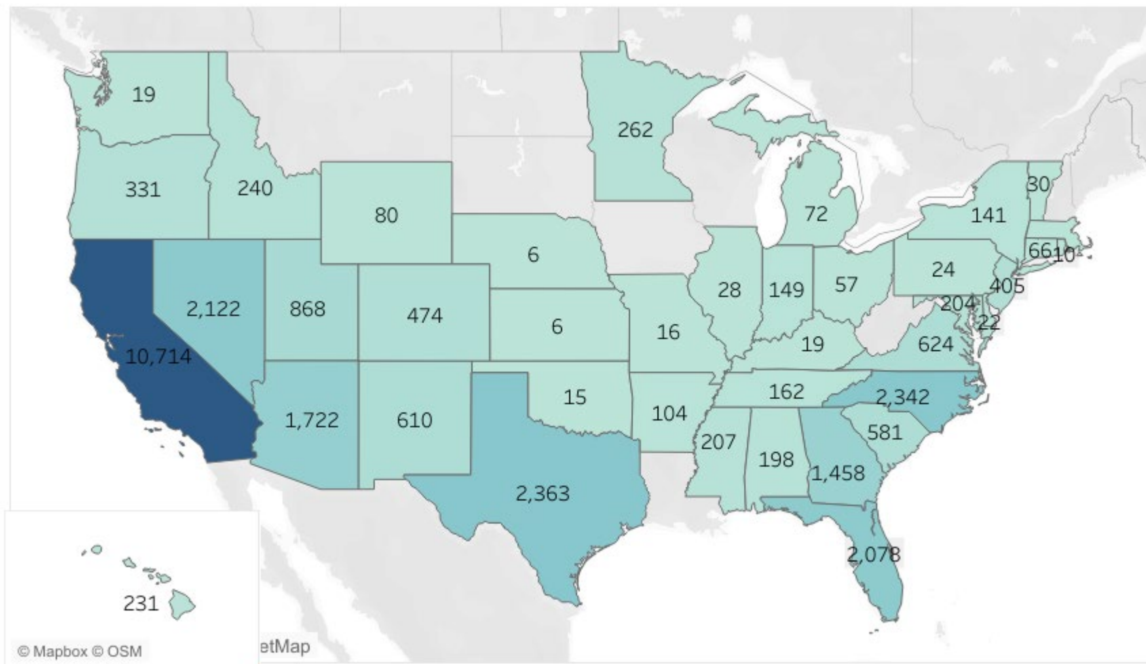

Figure 9. Cumulative utility PV capacity (MW) for all states as of 2019

Only states with more than 5 MW are shown. Image is from (Berkeley Lab, 2020).

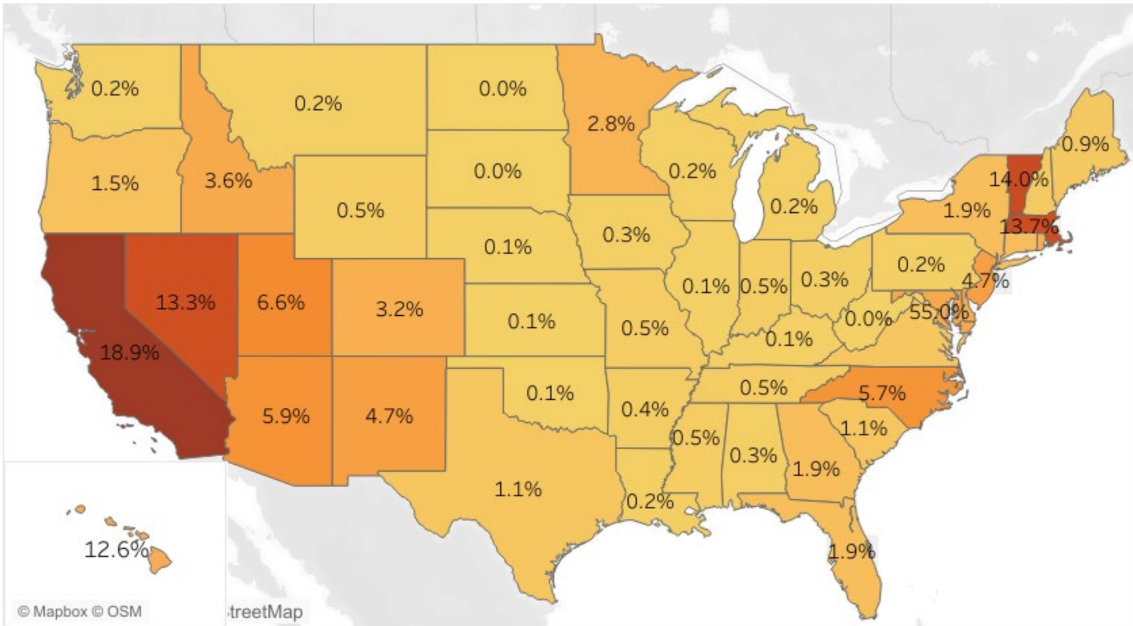

Figure 10. Percentage of in-state electricity generation as of 2019

Image is from (Berkeley Lab, 2020).

2.4 Future Work and Needs

The Solar Energy Technology Office (SETO) is working to address several challenges facing solar resource and technical potential in the United States. Some of those challenges SETO is addressing include the need to:

- **Better understand the availability of the solar resource in space and time:** Resource assessment and forecasting support the full gamut of solar project development and grid-integrated operation. Where historical resource assessments have previously informed financial viability of solar energy projects, the changing resource availability under climate change is likely to impact that practice. It is important to pair the National Solar Radiation Database measurements with global climate models that can resolve cloud cover to understand the effect of climate change on the future solar resource.
- **Increase the accuracy of solar resource forecasting methods:** Forecasting of solar radiation is one of the most effective ways to successfully integrate large quantities of solar power into the electric grid. However, multiday forecasting is computationally challenging. In a future with significant generation from solar, it will be important to forecast the solar resource over multiday horizons to optimize grid-operation responses, such as optimal energy storage use. The multiday horizon challenge will require closer collaboration with climate modelers, exploration of machine-learning and other artificial intelligence methods, and the support of significant computing capability.

- **Better understand where solar can be feasibly deployed when other types of land-use priorities are considered:** SETO is studying under what conditions solar PV can be co-located with agricultural production, on former industrial sites, and floating on water. SETO is examining the interaction of solar energy systems in local environments and with wildlife. By understanding the barriers that prevent solar from being deployed, and how those barriers can be mitigated, the realizable potential for solar energy can be more accurately assessed.
- **Clarify the changes in technical potential introduced by new technologies**:
  To increase solar energy generation in the United States, SETO is investing in technology improvements to increase solar efficiency and reliability while reducing costs of PV and CSP systems, addressing deployment challenges related to land-use and environmental considerations, ensuring solar energy benefits all Americans, and reducing costs and technical risks in the next generation of CSP plants.

3 Wind Energy

3.1 Summary of Wind Energy Potential

There is large potential for wind production in the United States, including a technical potential of 24,774 TWh annual electricity production from land-based wind (Lopez, et al., 2021), 19,290 TWh from offshore wind (Musial, Heimiller, Beiter, Scott, & Draxl, 2016) (Doubrawa, et al., 2017), and 4,400 TWh from distributed wind (Lantz, Sigrin, Gleason, Preus, & Baring-Gould, 2016). Table 5 shows the technical potential of wind energy resources, including the national capacity and energy production and the energy production within 10 miles of federally recognized Tribal lands. Figure 11 compares the annual energy production technical potential and 2020 energy production from wind resources. State-level analysis and detailed discussion of these values are found in the subsequent subsections.

Table 5. Technical Potential and Historical Generation of Wind Energy Resources

Resource	Potential Capacity in U.S. (GW)	Potential Energy Production in U.S. (TWh/yr)	Potential Energy Production near Tribal Lands (TWh/yr)	2020 Energy Production in U.S. (TWh/yr)
Wind: Land-Based	9,124	24,774	4,940	338
Wind: Offshore	5,075	19,290	[not assessed]	0
Wind: Distributed	3,000	4,400	[not assessed]	2*

U.S. capacity and energy production potential are from (Musial, Heimiller, Beiter, Scott, & Draxl, 2016) (Lantz, Sigrin, Gleason, Preus, & Baring-Gould, 2016) (Doubrawa, et al., 2017) (Lopez, et al., 2021). Energy potential that could be produced within 10 mi of federally recognized Tribal lands is from (Milbrandt, Heimiller, & Schwabe, 2018). 2020 energy production is preliminary data from (U.S. Energy Information Administration, 2021). The asterisk (*) indicates 2016 distributed energy production is from (Lantz, Sigrin, Gleason, Preus, & Baring-Gould, 2016).

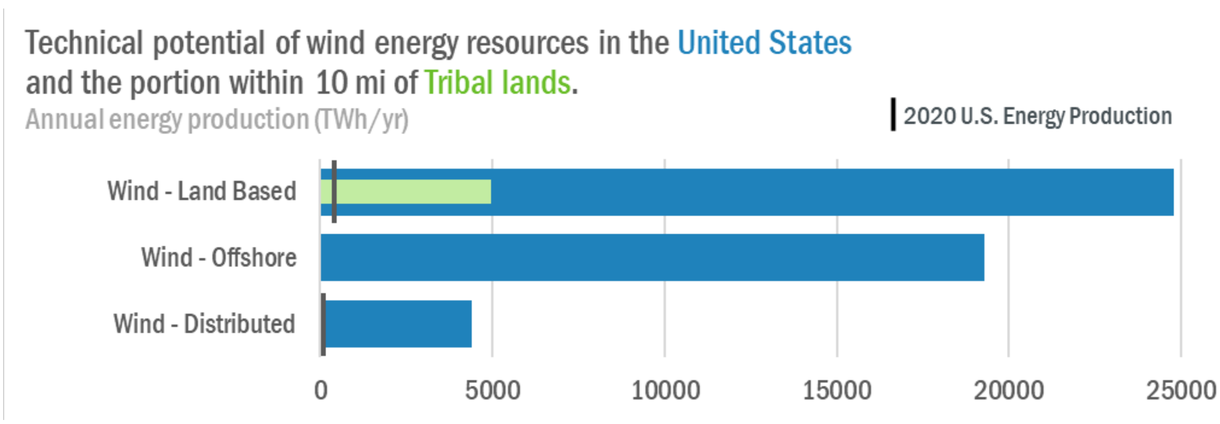

Figure 11. National energy production for wind energy resources

U.S. technical potential (outer bar) is from (Musial, Heimiller, Beiter, Scott, & Draxl, 2016), (Lantz, Sigrin, Gleason, Preus, & Baring-Gould, 2016), (Doubrawa, et al., 2017), and (Lopez, et al., 2021); technical potential within 10 mi of federally recognized Tribal lands (inner bar) is from (Milbrandt, Heimiller, & Schwabe, 2018); and 2020 energy production (line) is preliminary data from (U.S. Energy Information Administration, 2021). Offshore and distributed wind potential on Tribal lands were not estimated.

3.2 Introduction

The United States has a significant wind resource, particularly on the Central Plains and off the coast in the Northeast and Northwest. The available wind resource is quite variable both horizontally—along the ground—and vertically—above the ground. In general, wind resource increases with height above ground, but the rate of increase varies by local terrain and meteorology. Recent technological improvements have enabled taller wind turbines with larger rotors to capture more energy at greater heights above the ground.

The wind resource can also have significant diurnal and seasonal variations. The resource intensity can change rapidly over shorter periods, or it can remain quite steady. The degree of variability depends on local site characteristics and season. With advanced wind-forecasting techniques, the behavior of the wind at a particular location has a significant degree of predictability. Seasonal patterns of the wind resource can vary significantly among different regions of the United States and even within a region or state. Offshore wind resources generally display less diurnal variability, though inter-seasonal differences can still be significant depending on the location.

Wind turbines convert the kinetic energy of the wind into electricity. Wind turbine technology has advanced significantly over the past 10 years, with the United States increasing its wind power capacity 30% year over year (Wind Energy Technologies Office, 2020). Currently, land-based wind plants are located in 41 states, and they have created more than 100,000 jobs for Americans (Wind Energy Technologies Office, 2020). "The U.S. offshore wind resource is robust, abundant, and regionally diverse, allowing for offshore wind development that can be located near congested load centers that have some of the highest electric rates in the United States" (Musial, Heimiller, Beiter, Scott, & Draxl, 2016). While 42 MW of offshore wind are currently in operation in the United States, more than 28 gigawatts (GW) of offshore wind projects are in some stage of development (Musial, et al., 2020).[6]

[6] At the time of publication of (Musial, et al., 2020), a 30 GW Rhode Island facility was in operation and a 12 GW Virginia facility was under construction (now operational).

3.3 Potential Assessment

3.3.1 Resource Potential

NREL has maintained the Wind Integration National Dataset (WIND) Toolkit since 2014. It combines three different datasets to model the wind resource across North America, and it comprises wind speed and other meteorological data at a spatial resolution of 2 km and a temporal resolution up to 5 minutes at several levels from the ground to 160 m above ground (Draxl, Hodge, Clifton, & McCaa, 2015). The data are designed to be consistent with that required for day-ahead to 1-hour forecast horizons for the United States using industry best practices (Draxl, Hodge, Clifton, & McCaa, 2015). Wind speeds have diurnal and seasonal patterns. Wind speeds typically increase the higher from ground level one travels. As wind turbines have become taller, they have been able to access higher wind speeds. Typical wind turbines installed today have a hub height (the height to the center of the turning turbine blades) of 100 m, compared to a height of 30 m in 1990 (Wind Energy Technology Office, 2015). Hub height is expected to continue to increase with new technological advances.

Figure 12 shows the average annual wind resource in the CONUS at 100 m. The greatest land-based wind resource is found on the Central Plains, between the Rocky Mountains and Mississippi River. Higher and less variable wind speeds are found offshore in the Great Lakes, Gulf Coast, Atlantic Ocean, and Pacific Ocean, where winds can travel long distances without interruption by landmasses, even at low hub heights.

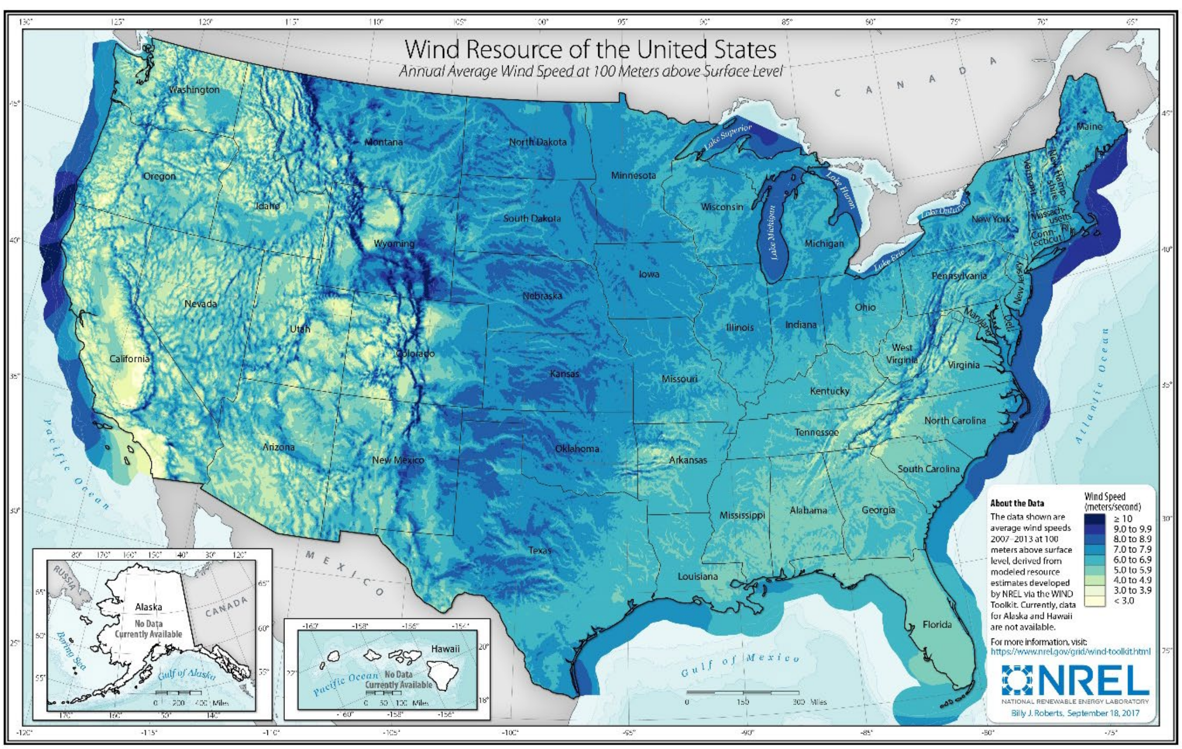

Figure 12. Wind resource in the CONUS at 100 m above the ground

Image is from (Draxl, Hodge, Clifton, & McCaa, 2015).

3.3.2 Technical Potential

3.3.2.1 Land-based Wind

Land-based wind energy has a large technical potential. There is an estimated total technical potential of 9.1 TW of capacity and 24,774 TWh of annual energy production in the United States given 2018 wind turbine technology (Lopez, et al., 2021).

Figure 13 shows the technical capacity potential of wind power across the CONUS (Lopez, et al., 2021). Wind power potential is predominantly on the Central Plains, where land-based wind resource is highest. As much as 16% of the land-based wind potential is located within 10 miles of recognized Tribal land (Milbrandt, Heimiller, & Schwabe, 2018). Technical potential estimates exclude environmentally sensitive areas (e.g., federally protected wetlands and forests) and land near urban areas and built infrastructure, such as roads. Wind potential in Figure 13 was calculated at a hub height of 120 m (Lopez, et al., 2021).

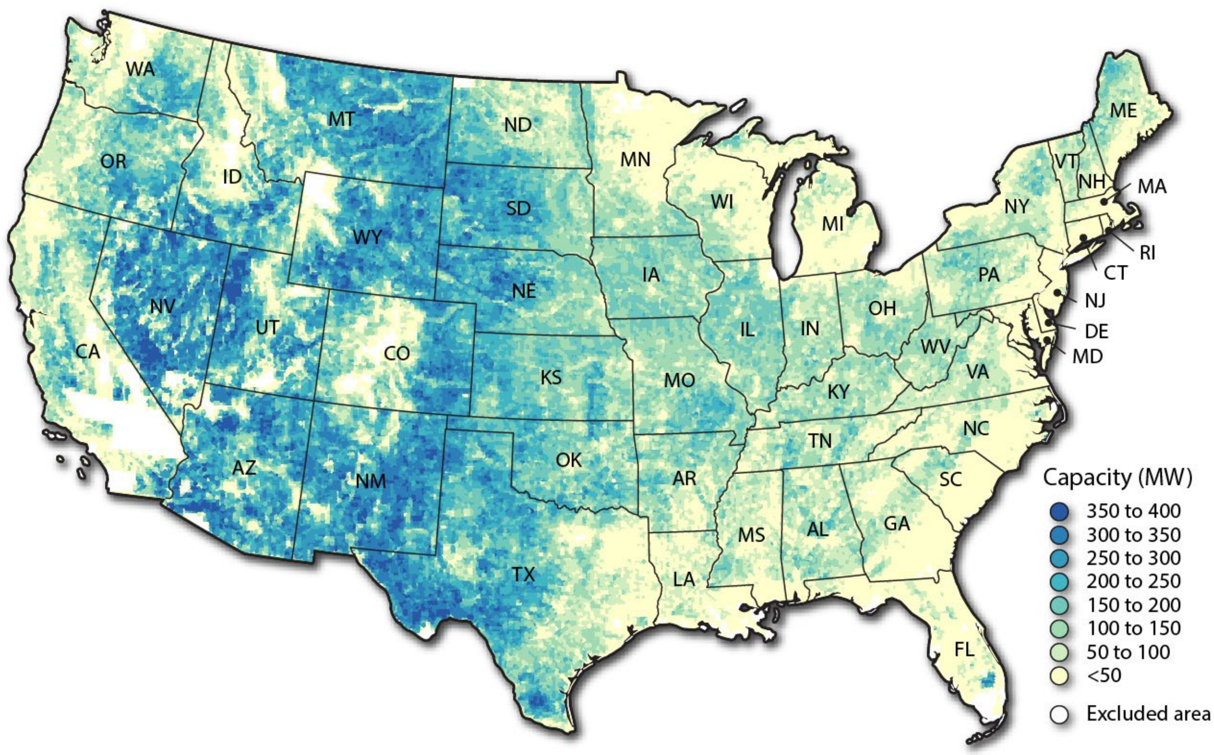

Figure 13. Technical capacity potential for land-based wind across CONUS assuming reference land restrictions

Image is from (Lopez, et al., 2021).

3.3.2.2 Offshore Wind

The technical potential of offshore wind is estimated to be 2.1 TW capacity and 7,203 TWh average annual energy production (Musial, Heimiller, Beiter, Scott, & Draxl, 2016). Assumptions of technical potential include a turbine hub height of 100 m, exclusion of deep Great Lakes waters most susceptible to icing, and consideration of sea floor depth, out to the edge of the U.S. exclusive economic zone at 200 nautical miles from shore (Musial, Heimiller, Beiter, Scott, & Draxl, 2016). Offshore wind technical energy potential is shown by state in Figure 14. Alaska has more offshore wind technical potential than the rest of the United States combined (Doubrawa, et al., 2017). The North Atlantic states have the most offshore wind potential outside Alaska (Musial, Heimiller, Beiter, Scott, & Draxl, 2016).

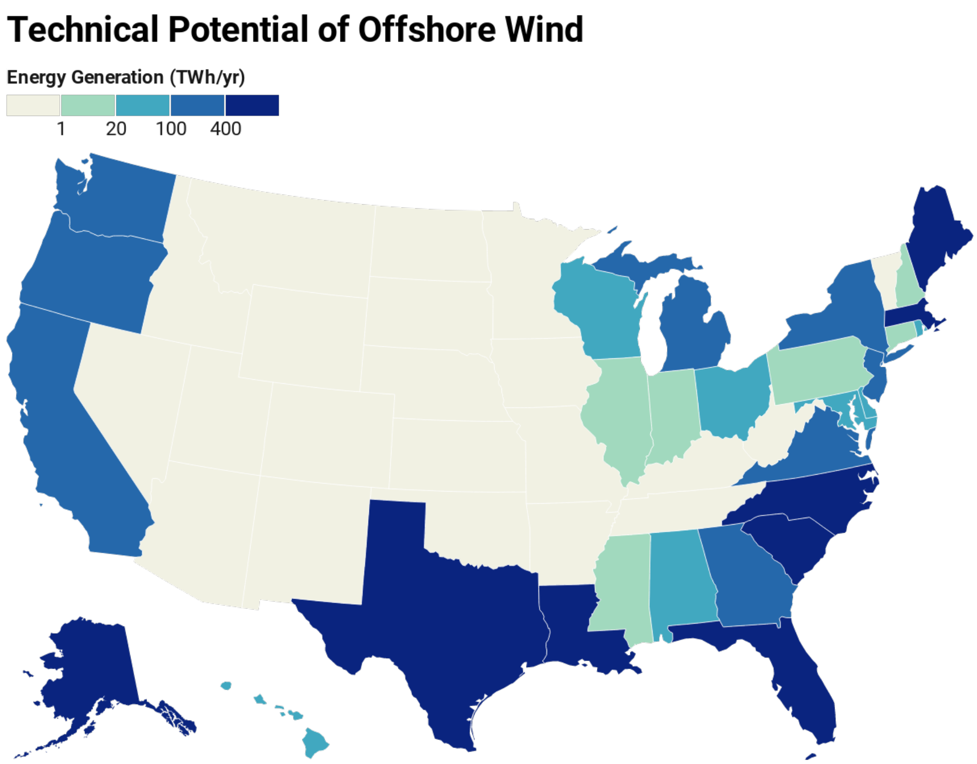

Figure 14. Annual energy production technical potential for offshore wind

CONUS and Hawaii data are from (Musial, Heimiller, Beiter, Scott, & Draxl, 2016) and Alaska data are from (Doubrawa, et al., 2017).

Accessing offshore wind resources poses more technical challenges than land-based wind. Though better wind resources maybe located farther offshore, the seafloor is also much deeper the further offshore one travels, making it very difficult to secure the turbines to the seafloor. DOE has increased research into floating wind turbine platforms so that these deep water offshore resources might be accessed. Underwater electric power cables must also be installed for offshore wind turbines to transmit the power back to shore. The longer those cables are to reach deep water turbines, the more expensive and complicated the project is.

3.3.2.3 Distributed Wind

Wind projects that are installed off-grid, behind-the-meter, and on the distribution system are considered distributed wind projects. Though the distributed wind market is smaller than that of utility-scale wind, the technical potential for distributed wind is sizable. Submegawatt-scale wind turbines could provide up 3.0 TW of capacity and 4,400 TWh of annual energy production (Lantz, Sigrin, Gleason, Preus, & Baring-Gould, 2016). The location of potential submegawatt-scale distributed wind is shown in Figure 15. The addition of distributed large, megawatt-scale turbines could double this technical potential, but these large turbines use land that would otherwise be viable for utility-scale land-based projects (Lantz, Sigrin, Gleason, Preus, & Baring-Gould, 2016).

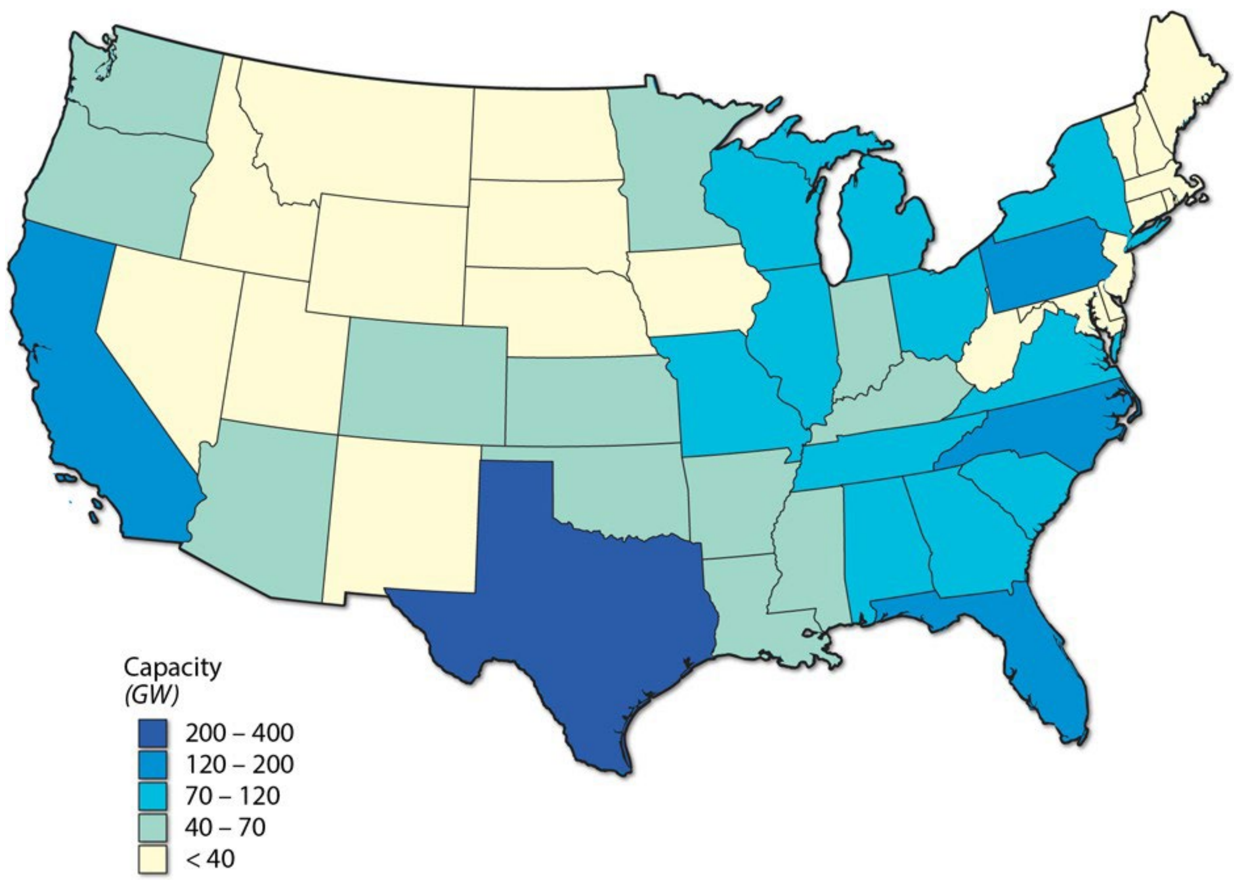

Figure 15. Technical capacity potential of submegawatt-scale distributed wind

Image is from (Lantz, Sigrin, Gleason, Preus, & Baring-Gould, 2016).

3.3.3 Installed Capacity

Land-based wind has been growing rapidly in recent years. In 2020, it contributed 337.5 TWh (preliminary data) to the national annual electricity mix, which represents a threefold increase from 94.7 TWh in 2010 (U.S. Energy Information Administration, 2021). Wind is installed in almost every state in the United States. Figure 16 shows current wind installations as of 2019 and cumulative capacity for each state.

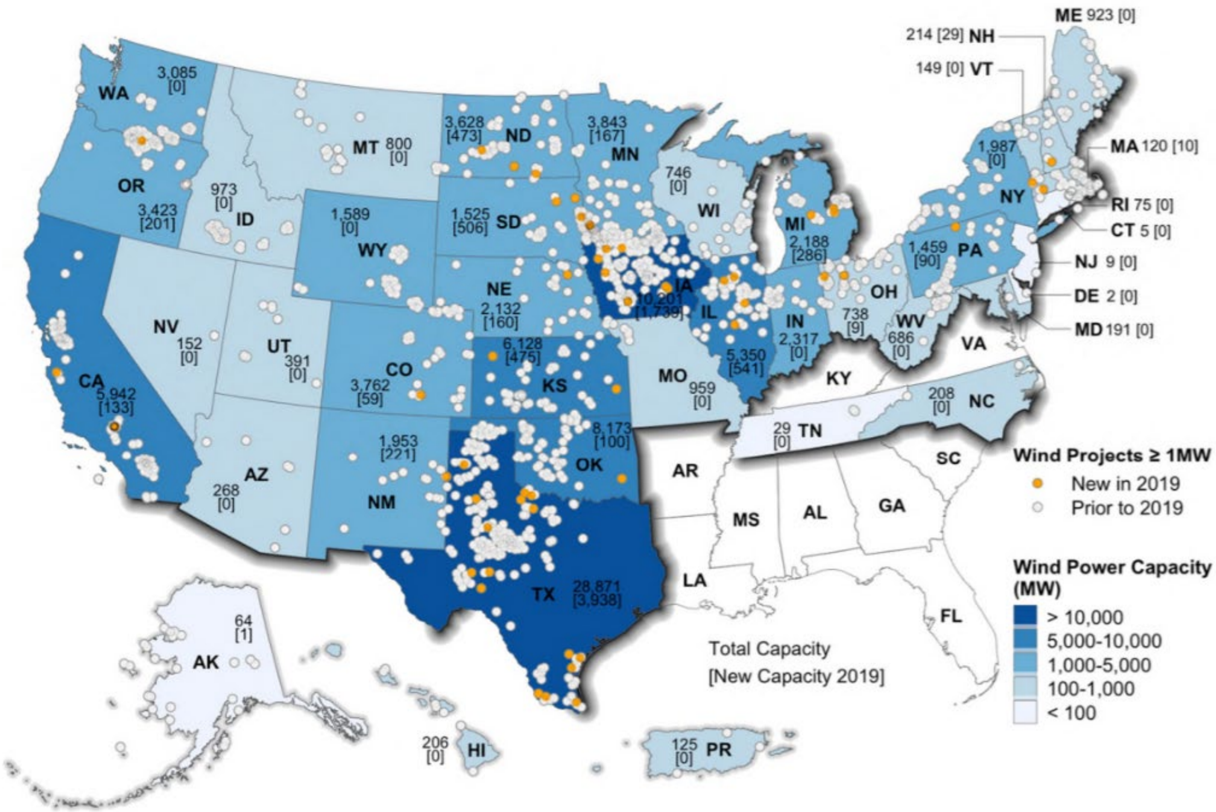

Figure 16. Location of installed land-based wind projects and capacity by state

Image is from (Wiser, et al., 2020).

Two offshore wind pilot plants are currently operating in the United States: one off Rhode Island and another off Virginia. Together, they comprise seven turbines totaling 42 MW. NREL's *2019 Offshore Wind Market Data Update* (Musial, et al., 2020) found more than 28,500 MW of announced offshore wind projects were in various stages of development (Musial, et al., 2020). Figure 17 shows the location, relative size, and development status of the full offshore wind pipeline in the United States.

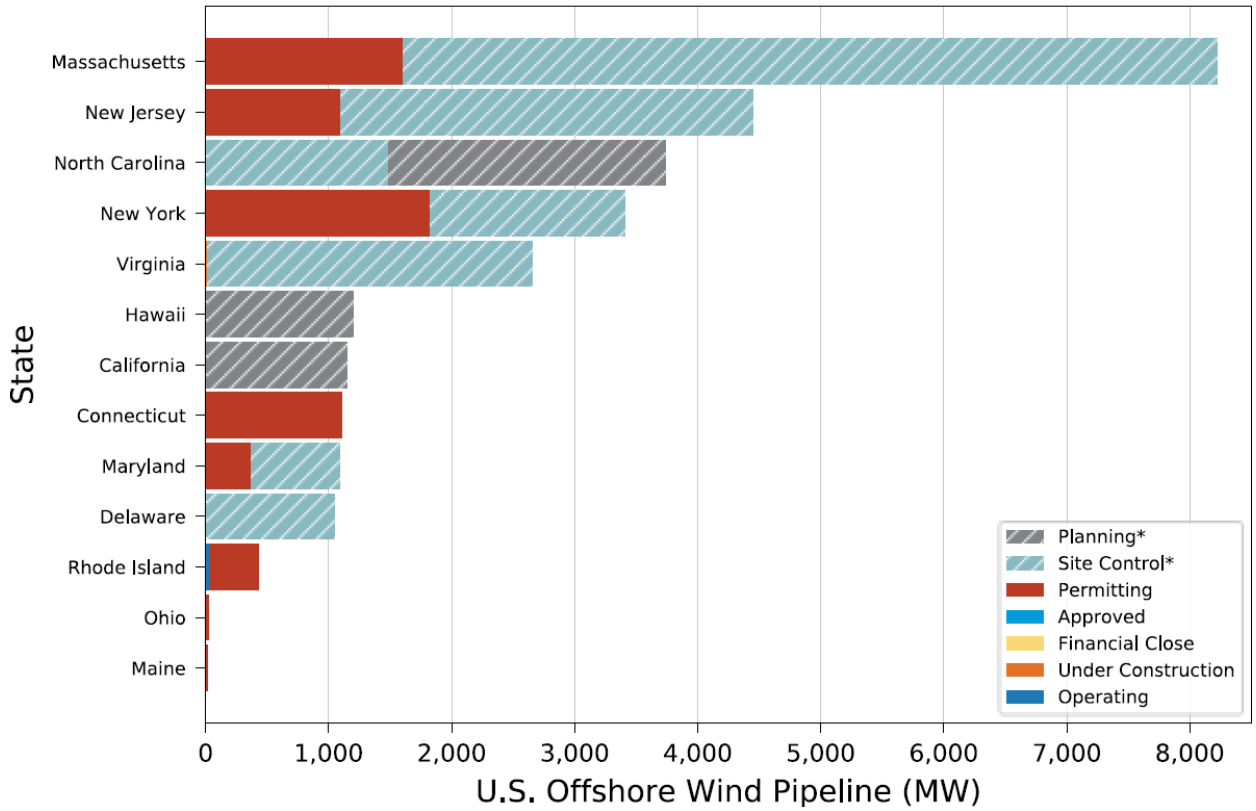

Figure 17. Cumulative capacity and development stage of all offshore wind projects by state

Asterisks indicate that lease area is assigned to state where lease area is located when power offtaker is not specified. Figure is from (Musial, et al., 2020).

3.4 Future Work and Needs

The Wind Energy Technology Office (WETO) is currently investing in several key innovations that could produce more accurate and useful representations of wind energy technical potential, and the technoeconomic and scenario analyses that rely on them. These key innovations include:

- **Replacing the current 7-year WIND Toolkit with a modern, 20-year mesoscale dataset:** The current WIND Toolkit has several limitations that have led WETO to begin development of a new set of long-term wind resource data; it includes no bias correction, it allows no evaluation of uncertainty, and the fact that it only includes 7 years of historical data (concluding in 2013) limits its usefulness in various kinds of energy analyses that require longer time series (e.g., evaluation of the impact of extreme weather events on the grid under different electricity sector future scenarios). WETO is currently developing a 20-year, bias-corrected dataset to replace the current WIND Toolkit and address these limitations.
- **Better representing siting constraints associated with wind energy development:** Current resource assessments do not adequately represent the spectrum of constraints that impact where and how wind plants may be built. WETO is working with various

stakeholders and improving the models it uses to better reflect state and local permitting requirements, wildlife impacts, radar and airspace impacts, and other siting considerations. Such improvements will enable resource assessments and modeling scenarios that better reflect the reality of siting wind energy, and they will allow for the evaluation of innovations (e.g., environmental mitigation measures) that might reduce these siting constraints.

- **Developing the capacity to evaluate wind resource technical potential with site-specific wind turbine and plant technology:** Current resource assessments currently use crude assumptions about power density (currently 3 MW/km^2) and blanket representations of wind turbine technology. In reality, power density and wind technology vary greatly depending on site conditions. WETO is investing in various tools to enable the representation of site-specific wind plant and turbine characteristics at the national laboratories, both to enable more accurate characterization of wind energy technical and economic potential, and to evaluate various innovations for how they could affect both resource potential and wind deployment.
- **Access to transmission for offshore wind:** Assessment of transmission siting and feasibility can further inform the potential resource availability for offshore wind.

4 Biomass Energy

4.1 Summary of Biomass Energy Potential

Electricity from biomass resources is a mature industry, and biomass is a geographically diverse resource found in most regions of the United States. There is potential for producing 505 TWh of annual electric energy from biomass in the United States (Brown, et al., 2016).[7] Table 6 shows the technical potential of biomass energy resources, including the national capacity and energy production and the energy production within 10 miles of federally recognized Tribal lands. Figure 18 compares the annual energy production technical potential and 2020 deployment. State-level analysis and detailed discussion of these values are found in the subsequent subsections.

Table 6. Technical Potential and Historical Generation of Biomass Energy Resources

Resource	Potential Capacity in U.S. (GW)	Potential Energy Production in U.S. (TWh/yr)	Potential Energy Production near Tribal Lands (TWh/yr)	2020 Energy Production in United States (TWh/yr)
Biomass	71	505	20	56

U.S. capacity and energy production potential are from (U.S. Department of Energy Office of Energy Efficiency and Renewable Energy, 2014) and (Brown, et al., 2016). Energy potential that could be produced within 10 mi of federally recognized Tribal lands is combined woody solid and distributed biogas from (Milbrandt, Heimiller, & Schwabe, 2018). 2020 energy production is preliminary data from (U.S. Energy Information Administration, 2021).

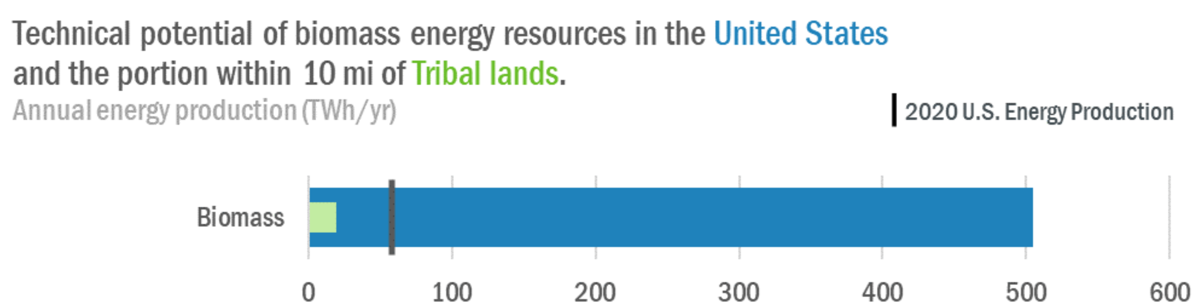

Figure 18. National energy production for biomass energy resources

U.S. technical potential (outer bar) is from (Brown, et al., 2016), technical potential within 10 mi of federally recognized Tribal lands (inner bar) is from (Milbrandt, et al., 2018), and 2020 energy production (line) is preliminary data from (U.S. Energy Information Administration, 2021).

[7] Technical potential used here includes total developed and undeveloped potential listed in (Brown, et al., 2016).

4.2 Introduction

Biomass is a versatile renewable energy source. It can be derived from plant- and algae-based materials, including crop wastes, forest residues and waste, grasses, energy crops, urban wood waste, municipal solid waste, and microalgae. Bioenergy technologies enable the reuse of carbon from biomass and waste streams into several end-use commodities, including bioproducts, less carbon intensive transportation fuels, and renewable electricity. Biomass differs from other renewable energy resources because electricity is only one of many possible end uses. An inventory of biomass feedstock sources and end uses are shown in Figure 19 (Oak Ridge National Laboratory, 2016).

In 2015, biomass for electricity production, also called biopower, made up 18% of all energy end uses for biomass (Oak Ridge National Laboratory, 2016). The major feedstock sources for electricity production are solid biomass (forests, primary and secondary mill residues, urban wood waste, municipal solid waste, and crop residues) and gaseous biomass (methane emissions from manure, wastewater treatment plant emissions, and landfill gases). This report considers only the ability of biomass resource to produce electricity, though DOE has estimated the technical potential of biomass for other end uses as shown in Figure 19.

The demand for biomass feedstocks by consumption sectors is in a constant state of change. For example, wood and wood waste that was once used as a feedstock for the pulp and paper industry is now being exported as wood pellets for the production of biopower, and in the future with changing policies could be used for the use in the production of sustainable aviation fuel. The supply dynamic for biomass feedstocks is not fully captured in the studies presented in this report, but they could be captured in future reports as technical potential assessments for biomass energy are updated.

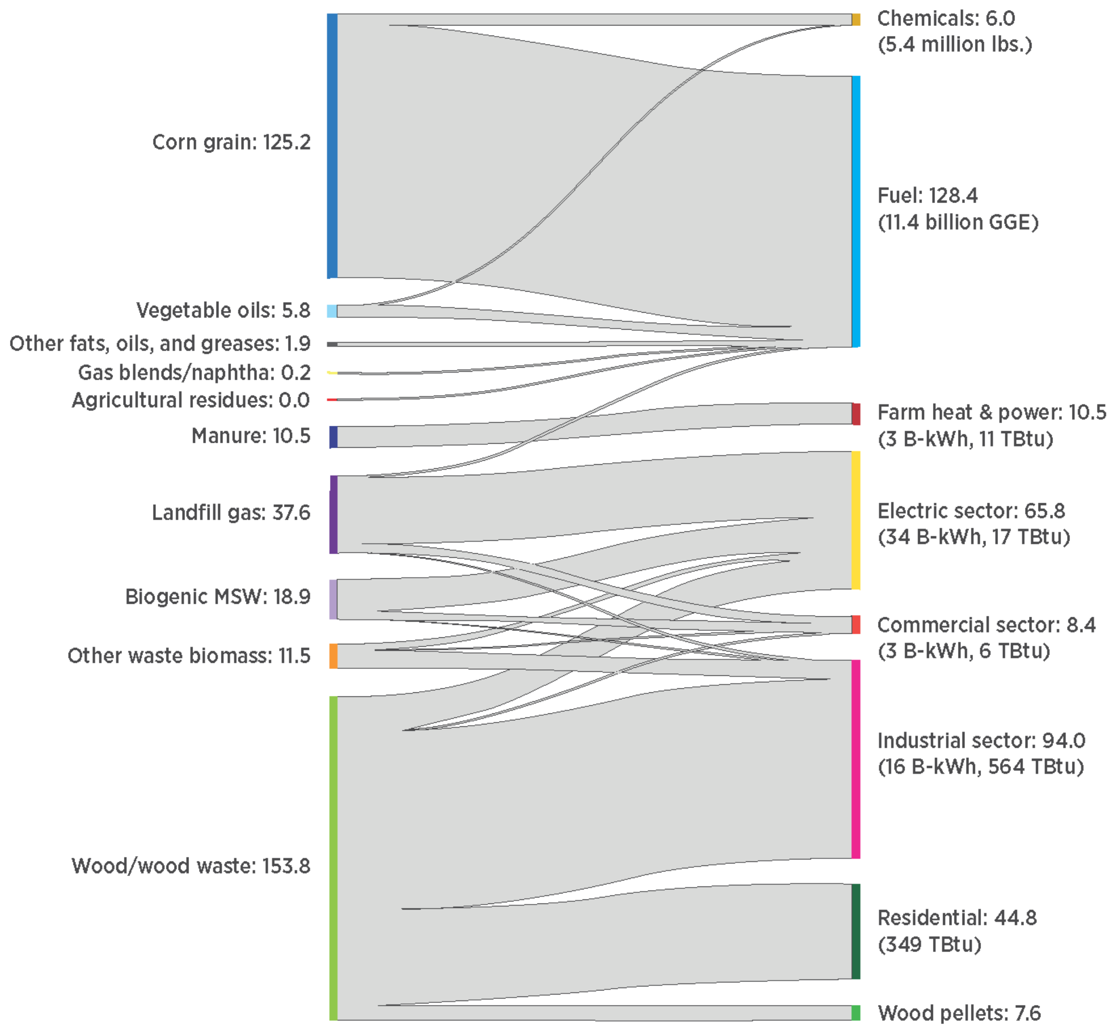

Figure 19. Inventory of biomass feedstock sources (left) and end-use sector consumption (right), in million dry tons per year

Figure is from (Oak Ridge National Laboratory, 2016).

4.3 Potential Assessment

4.3.1 Resource Potential

Recent resource potential studies have focused on the methane resource from landfills; wastewater treatment plants; livestock; and the industrial, institutional, and commercial sectors. Figure 20 shows the total methane resource potential by county in the United States (Saur & Milbrandt, 2014). Landfills and wastewater treatment plants make up over 80% of the 16 million tons of methane resource potential (Saur & Milbrandt, 2014). The location and size of landfills and wastewater treatment plants that produce methane are shown in Figure 21 (Milbrandt, Bush, & Melaina, 2016). Oak Ridge National Laboratory performed resource assessments of solid biomass sources as part of their *2016 Billion-Ton Report* (Oak Ridge National Laboratory, 2016), but these data are presented as economic potential and outside the scope of this summary report.

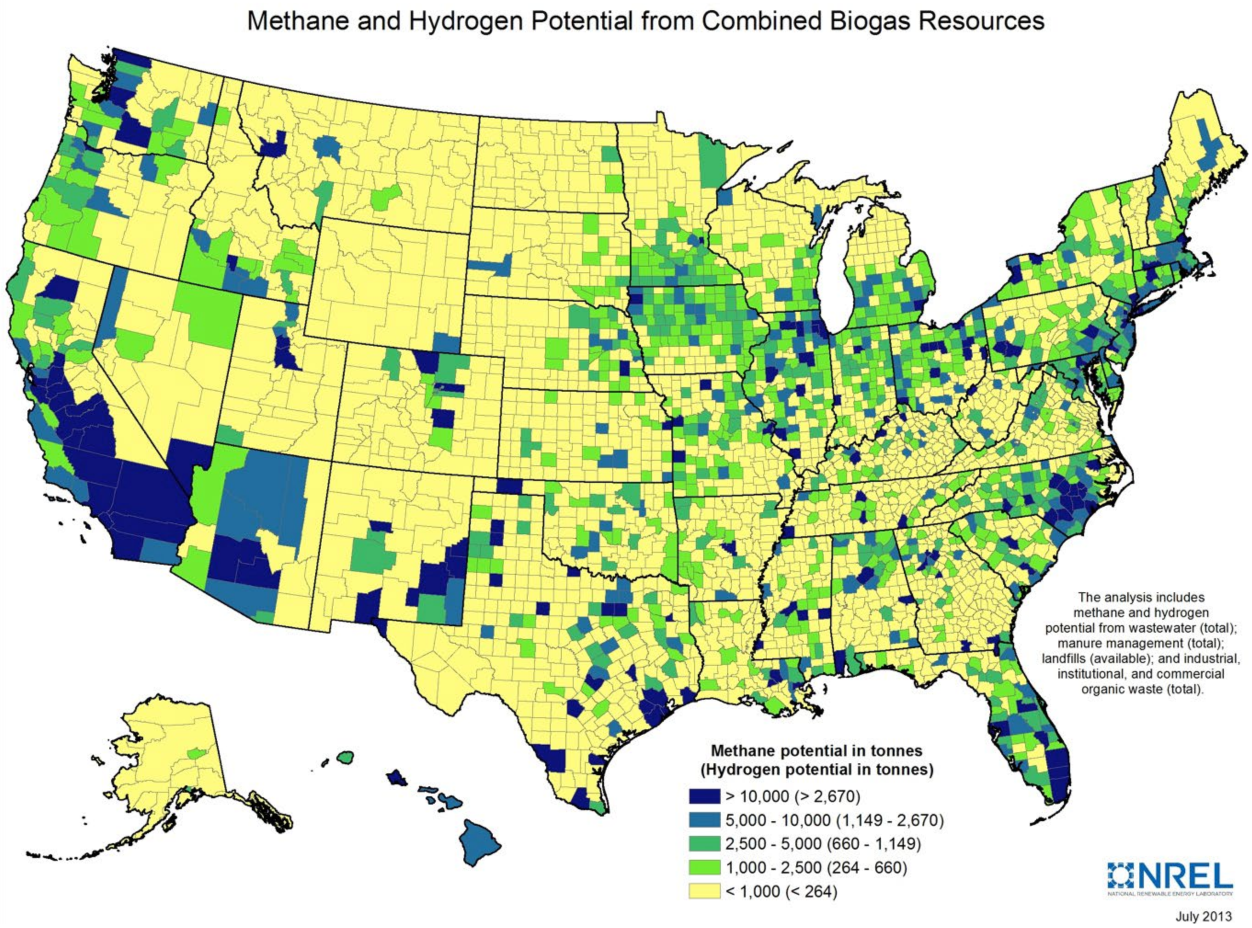

Figure 20. Methane resource potential from combined biogas sources in the United States by county

Image is from (Saur & Milbrandt, 2014), which also reported the technical potential of hydrogen production.

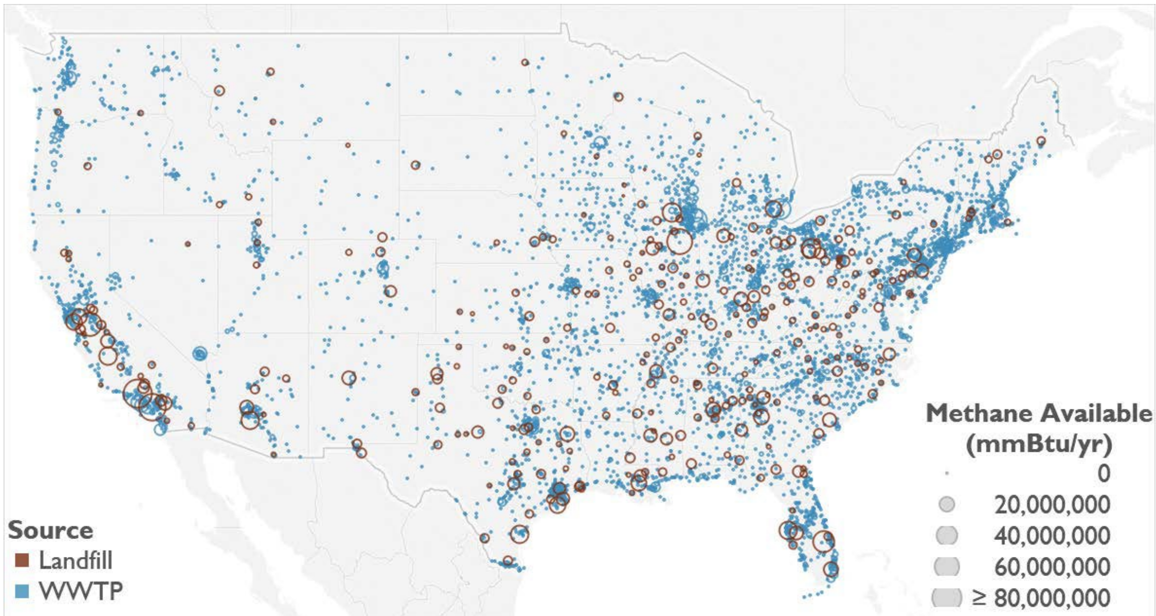

Figure 21. Potential methane production from biogas at landfills and wastewater treatment plants

Figure is from (Milbrandt, Bush, & Melaina, 2016)

4.3.2 Technical Potential

The technical potential of solid and gaseous biomass sources has been calculated separately. In 2012, researchers at NREL calculated a technical potential of 62 GW capacity and 488 TWh annual energy production (Lopez, Roberts, Heimiller, Blair, & Porro, 2012). Of this total energy production, 82% came from solid biomass sources and 18% came from gaseous sources. An estimated 17 TWh/yr of woody biomass and 2.7 TWh/yr of biogas technical potential is available within 10 miles of Tribal lands (Milbrandt, Heimiller, & Schwabe, 2018). In 2016, NREL researchers updated the assumptions for solid biomass used in the 2012 technical potential study. The updated study estimates there is 56 GW capacity and 445 TWh annual energy production of solid biomass technical potential in addition to what was already deployed in 2013 (Brown, et al., 2016).

Biomass potential is geographically diverse. The technical potential for electricity production from biomass for every state is shown in Figure 22. The figure shows data from the 2012 study because state-level data were not calculated in subsequent potential studies.

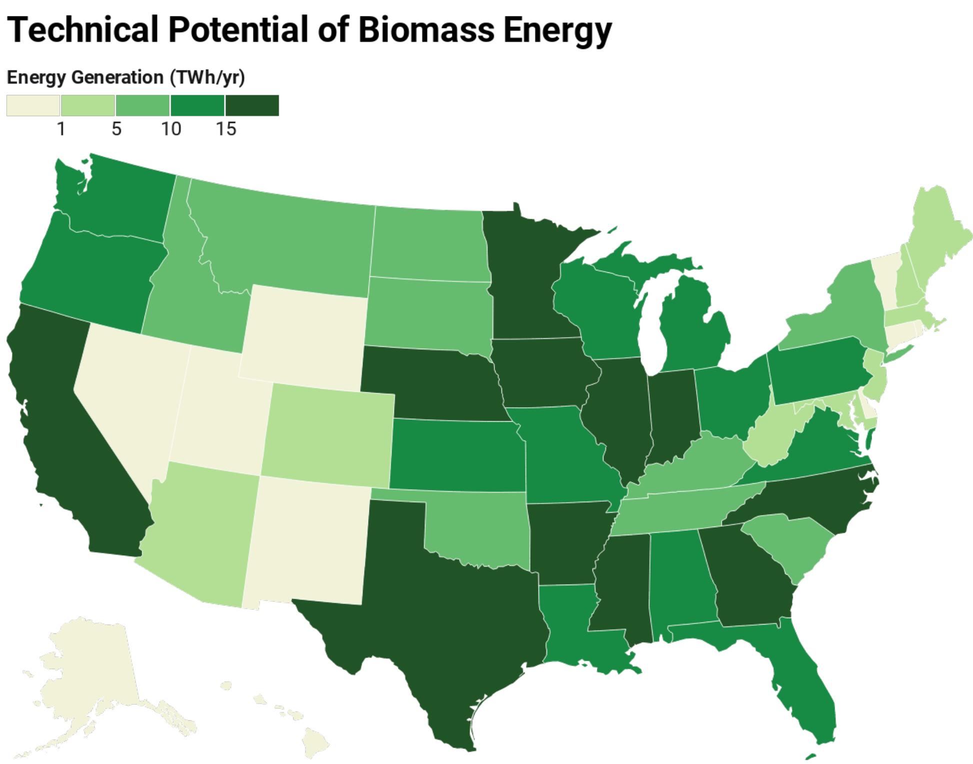

Figure 22. Annual energy production technical potential for biomass energy

Data are from (Lopez, Roberts, Heimiller, Blair, & Porro, 2012).

4.3.3 Installed Capacity

"Biomass electricity generation accounts for 12% of all renewable energy generated in the United States and about 1.6% of total U.S. electricity generation" (Bioenergy Technologies Office, 2017). Though "the installed biopower capacity has been increasing over the past 10 years, biopower generation has remained almost flat during that period. The total number of biopower plants increased from 485 in 2003 to 760 in 2015" (Bioenergy Technologies Office, 2017). "In 2015, the top five states with the largest biopower generation were California, Florida, Georgia, Virginia, and Maine." Figure 23 shows the growth of biomass for electricity production between 2006 and 2015. In 2020, biomass contributed 56 TWh to the nation's electricity mix (U.S. Energy Information Administration, 2021).

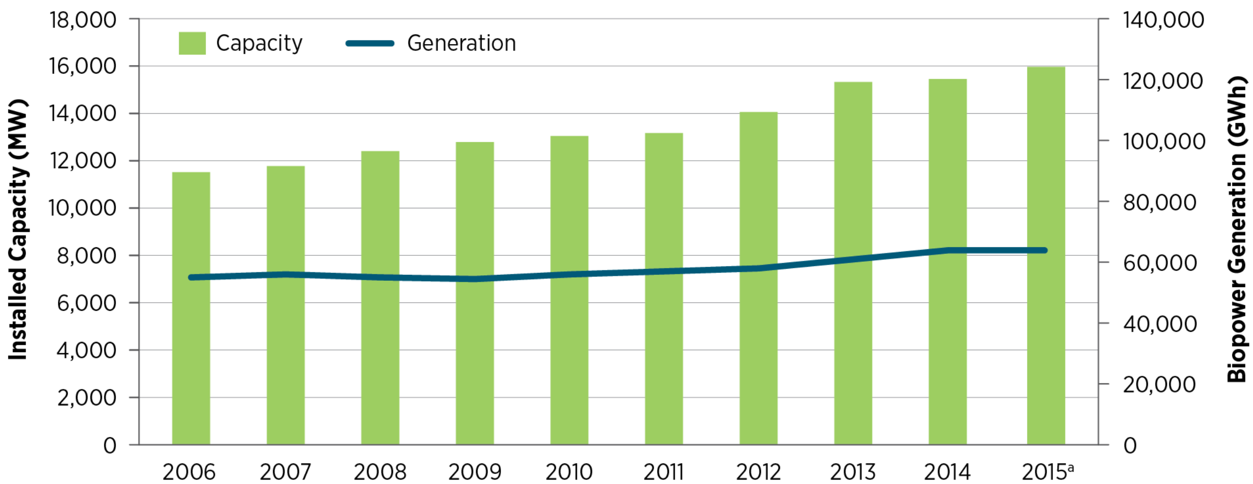

Figure 23. U.S. biomass for electricity capacity and generation from 2006 to 2015

Image is from (Bioenergy Technologies Office, 2017)

4.4 Future Work and Needs

The Bioenergy Technologies Office (BETO) is funding research and analysis to advance the use of biomass and waste as feedstocks to produce biofuels, including sustainable aviation fuels and marine diesel, electric power, biochemicals, and environmental services. Future work and analysis needs include the following:

- **Advance the findings from the 2016 Billion-Ton Study**: The 2016 Billion-Ton Study identified biomass and organic resources, and the amounts that could be mobilized for use as biofuel feedstocks under several cost and logistics scenarios (Oak Ridge National Laboratory, 2016). The data resource developed from the original analysis will be used to assess potential benefits related to carbon sequestration, greenhouse gas emission reductions, ecosystem services, and environmental justice concerns. In addition, other end uses, such as bioenergy with carbon capture and storage, and biomass power production, of the mobilized biomass will be evaluated.
- **Better understand the availability of municipal solid waste for use as a biomass feedstock:** Understanding the variability of municipal solid waste characteristics is

critical to inform the steps needed to produce conversion-ready feedstocks. Characterization includes measurement across multiple features (chemical, physical, and biological), scales (macro, micro, and molecular), speeds (including rapid/real-time measurements on a conveyor), sites, and periods (seasons and years). Harmonization of municipal solid waste resource assessments with other biomass resources assessments is also needed.

- **Expand resource assessment to commercially available feedstocks**: BETO is expanding the scope of biomass feedstock assessment to include commercially available feedstocks including sugar/starch and vegetable oil/tallow. Of particular interest in the near term is analysis of commercial vegetable oil seed crop production to enable market pull for renewable diesel and sustainable aviation fuel demand.
- **Better understand barriers to biomass production and collection**. There is a need to quantify the potential for novel integrated landscape management and design to provide (1) opportunities for the production of dedicated energy crops and (2) other environmental and economic benefits by capitalizing on subfield variability, reducing inefficiencies, and valuing ecosystem services.

5 Ocean Energy

5.1 Summary of Ocean Energy Potential

Energy from the ocean's waves, currents, tides, and thermal differences have large potential for electricity production. Ocean energy technology is a nascent industry with only a few pilot projects in operation. Studies estimate there is potential for producing 2,300 TWh of annual electricity from ocean resources off U.S. shores (Kilcher, Fogarty, & Lawson, 2021). Table 7 shows the technical potential of ocean energy resources considered in this report. Figure 24 compares the annual energy production technical potential and historical 2020 energy production for all ocean resources. State-level analysis and detailed discussion of these values are found in the subsequent subsections. We use "ocean" energy here to align with the EPAct 2005 language, but note that "marine" energy is increasingly common terminology in the industry.

Table 7. Technical Potential and Historical Generation of Ocean Energy Resources

Resource	Potential Energy Production in U.S. (TWh/yr)	2020 Energy Production in U.S. (TWh/yr)
Ocean	2,300	0

Data are from (Kilcher, Fogarty, & Lawson, 2021) and (U.S. Energy Information Administration, 2021) (preliminary data).

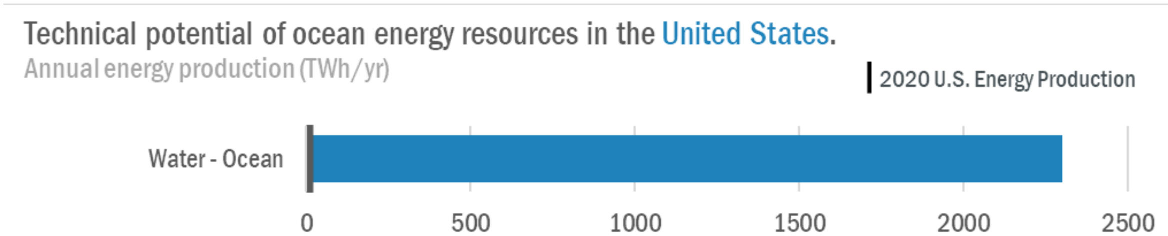

Figure 24. National energy production for ocean energy resources

U.S. technical potential (horizontal blue bar) from (Kilcher, Fogarty, & Lawson, 2021) and 2020 energy production (line) is preliminary data from (U.S. Energy Information Administration, 2021). Ocean energy potential on Tribal lands was not assessed.

5.2 Introduction

Ocean energy has historically focused on the energy of the ocean's waves. The Energy Act of 2020 defined marine energy as energy from waves, tides, ocean currents, free-flowing rivers, human-made channels, as well as from differentials in salinity, temperature, and pressure (Kilcher, Fogarty, & Lawson, 2021). Energy from waves off U.S. coasts is much higher than the other ocean energy sources, but all sources are considered here.

Cost and technological challenges make harnessing ocean energy potential for electricity difficult. Ocean energy technologies are at an early stage of development because of the fundamental challenges of generating power from a dynamic, low-velocity, and high-density resource while withstanding corrosive marine environments. These challenges are intensified by high costs and lengthy permitting processes associated with in-water testing (Water Power Technologies Office, 2020).

5.3 Potential Assessment

5.3.1 Resource Potential

"The theoretical ocean wave energy resource potential exceeds 50% of the annual domestic energy demand of the United States, is located close to coastal population centers, and, although variable in nature, may be more consistent and predictable than some other renewable generation technologies. As a renewable electricity generation technology, ocean wave energy offers a low air pollutant option for diversifying the U.S. electricity generation portfolio. Furthermore, the output characteristics of these technologies might complement other renewable technologies" (Previsic, et al., 2012).

Two ocean wave resource potential studies were published in 2011 and 2012. The first report estimated a total resource potential of 2,640 TWh/yr average energy production (Electric Power Rearch Institute, 2011). This calculation was conducted assuming a depth of 200 m below sea level. The second study revised this assessment to a more practical depth of 100 m. The 2012 study estimated a resource potential of 1,849 TWh/yr (Previsic, et al., 2012). The lowered resource potential is due mostly to the shallower depth assumption. Figure 25 shows the average wave power density off U.S. coasts from the 2012 study.

NREL compiled the resource potentials of the five ocean energy resources as defined in the Energy Act of 2020 for all U.S. states. And NREL calculated the wave energy resource off U.S. coasts out to the U.S. exclusive economic zone to be 3,300 TWh/yr (Kilcher, Fogarty, & Lawson, 2021). This calculation is much higher than the previous studies in large part due to the increased distance from shore considered.

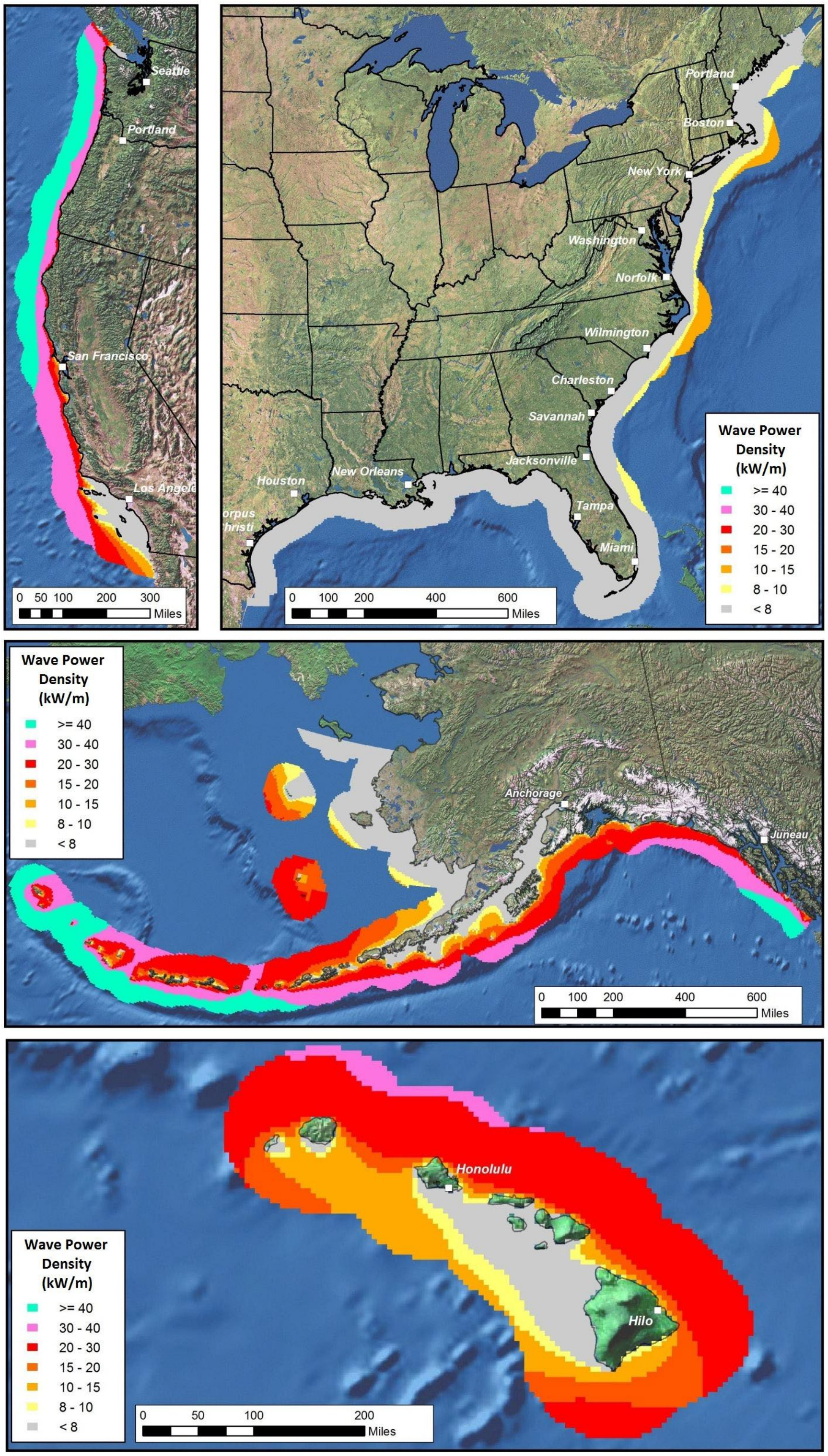

Figure 25. Annual average wave power density (kW/m) off U.S. coasts

Image is from (Previsic, et al., 2012)

5.3.2 Technical Potential

In addition to calculating the resource potential of wave energy off U.S. coasts, (Electric Power Rearch Institute, 2011) and (Previsic, et al., 2012) also calculated the technical potential. The first study found a technical potential of 1207 TWh/yr energy production at a depth of 200 m (Electric Power Rearch Institute, 2011).[8] The second study found a technical potential of 961 TWh/yr energy production at a depth of 100 m (Previsic, et al., 2012). Both studies calculated the technical potential for several different scenarios and assumptions about technology deployment. Figure 26 shows the technical potential for wave energy at a depth of 200 m by state given data from the 2011 study.

The 2021 NREL study found comparable technical potential for wave energy of 1,400 TWh/yr when measured out to the U.S. exclusive economic zone (Kilcher, Fogarty, & Lawson, 2021). In addition, NREL calculated technical potentials of 220 TWh/yr in tidal energy, 49 TWh/yr in ocean current energy, 540 TWh/yr in ocean thermal energy, and 99 TWh/yr in river current energy (Kilcher, Fogarty, & Lawson, 2021). These total 2,300 TWh of annual technical energy potential for the United States. The regional ocean energy resources are shown in Figure 27.

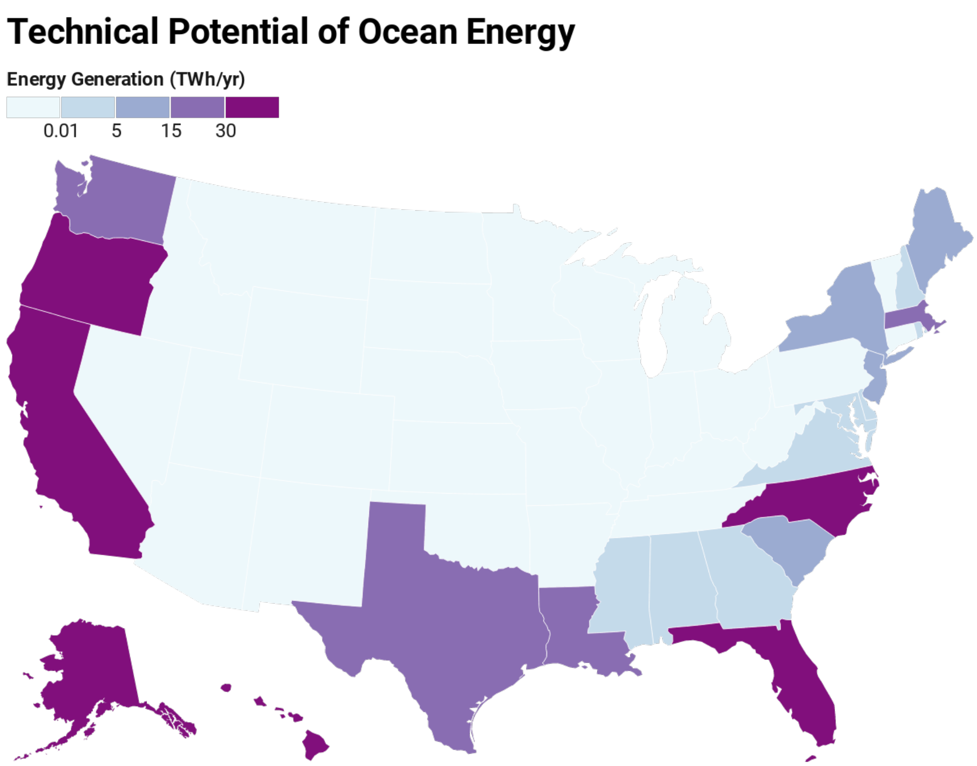

Figure 26. Annual energy production technical potential for ocean wave energy

Data are from (Electric Power Rearch Institute, 2011) using 10 MW/km packing assumptions.

[8] Calculated as the sum of all states' technically recoverable resource on the outer shelf and packing density of 15 MW/km from Section 6 of (Electric Power Rearch Institute, 2011)

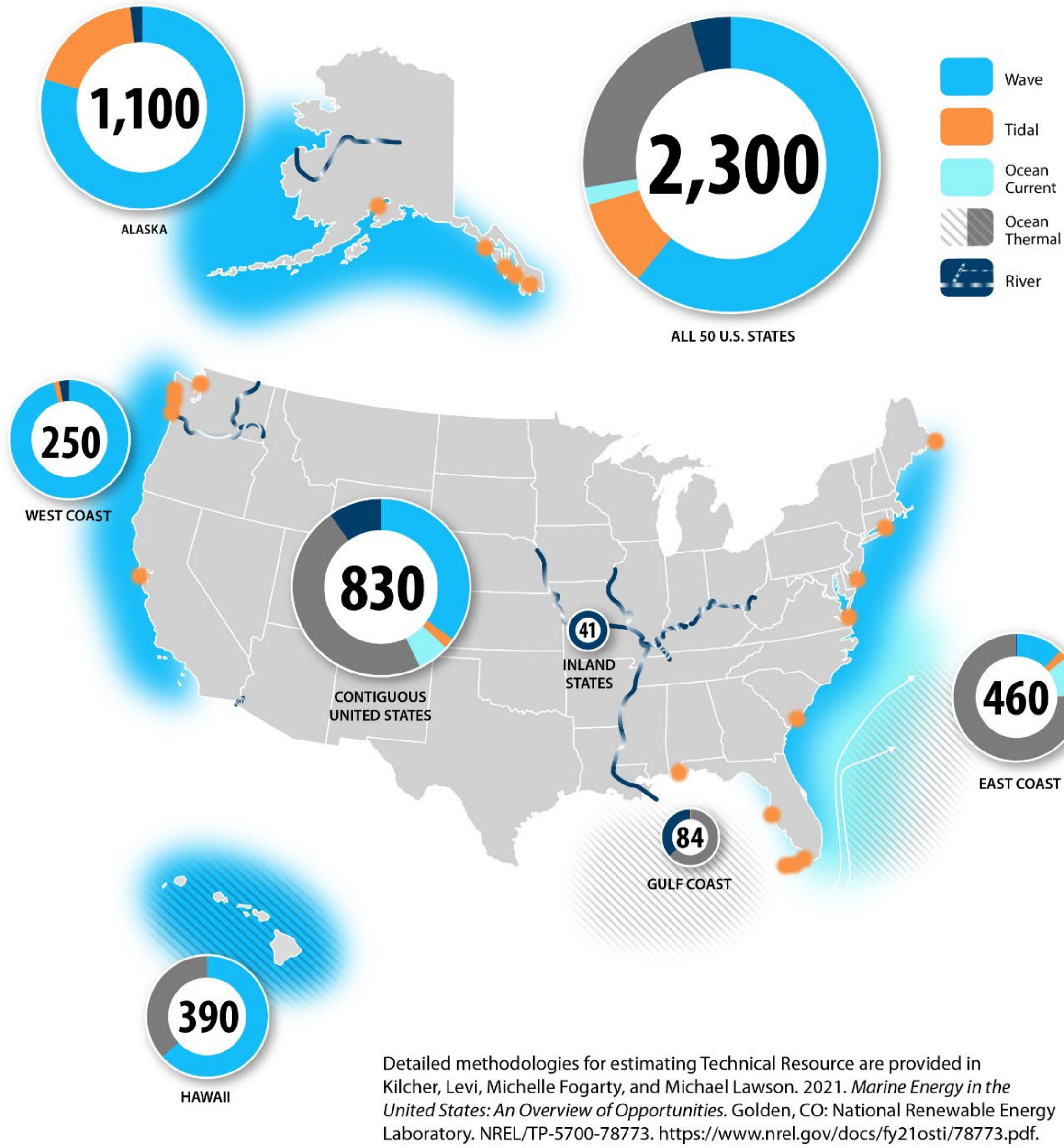

Figure 27. Annual technical energy potential (TWh/yr) of the five key ocean energy resources available to the United States

Image is from (Kilcher, Fogarty, & Lawson, 2021).

5.4 Future Work and Needs

The Marine Energy Program at the Water Power Technologies Office (WPTO) comprises four core research and development (R&D) activity areas that represent the program's strategic approach to addressing the challenges faced by U.S. marine energy stakeholders. Work in these four areas will help the United States realize its technical ocean energy potential:

- **Foundational R&D:** drive early-stage R&D focused on components, controls, manufacturing, and materials; develop and validate numerical modeling tools; improve resource assessments and characterizations; develop and apply quantitative metrics to identify and evaluate devices' potential

- **Technology-Specific System Design and Validation:** validate performance and reliability of systems through prototype testing, including in-water testing; improve cost-effective methods for installation, operation, and maintenance (IO&M); support the development and adoption of international standards for device performance and insurance certification; evaluate existing and potential needs for ocean energy-specific IO&M infrastructure
- **Reducing Barriers to Testing:** enable access to world-class testing facilities; ensure existing data are accessible and used by regulators; focus research on mitigating environmental risks and reducing the cost and complexity of permitting and environmental monitoring; engage in relevant coastal planning processes to ensure ocean energy interests are considered
- **Data Access and Analytics:** provide original research to assess and communicate potential marine and hydrokinetic market opportunities, including those relevant for other maritime markets; aggregate and analyze data on marine and hydrokinetic performance and technology advances, and maintain information sharing platforms to enable dissemination; leverage expertise, technology, data, methods, and lessons learned from the international marine and hydrokinetic community and other offshore scientific and industrial sectors.

6 Geothermal Energy

6.1 Summary of Geothermal Energy Potential

There are two general categories of geothermal technologies for electricity production: hydrothermal and enhanced geothermal systems (EGS). Hydrothermal technologies are a mature technology with power plants in operation in the western United States. EGS is a nascent technology with technical potential throughout the United States. There is an estimated 181 TWh of annual energy technical potential from hydrothermal resources and 24,638 TWh from EGS.[9] Table 8 shows the technical potential of all geothermal energy resources, including the national capacity and energy production and the energy production within 10 miles of federally recognized Tribal lands. Figure 28 compares the annual energy technical potential and historical 2020 production. State-level analysis and detailed discussion of these values are found in the subsequent sections.

Table 8. Technical Potential and Historical Generation of Geothermal Energy Resources

Resource	Potential Capacity in U.S. (GW)	Potential Energy Production in U.S. (TWh/yr)	Potential Energy Production near Tribal Lands (TWh/yr)	2020 Energy Production in U.S. (TWh/yr)
Geothermal - Enhanced	3,377	24,638	[not assessed]	0
Geothermal - Hydrothermal	24	181	4	17

U.S. capacity and energy production potential are from (Augustine, Ho, & Blair, 2019), raw data provided to DOE for this report. Energy potential that could be produced within 10 mi of federally recognized Tribal lands from (Milbrandt, Heimiller, & Schwabe, 2018). 2020 energy production is preliminary data from (U.S. Energy Information Administration, 2021).

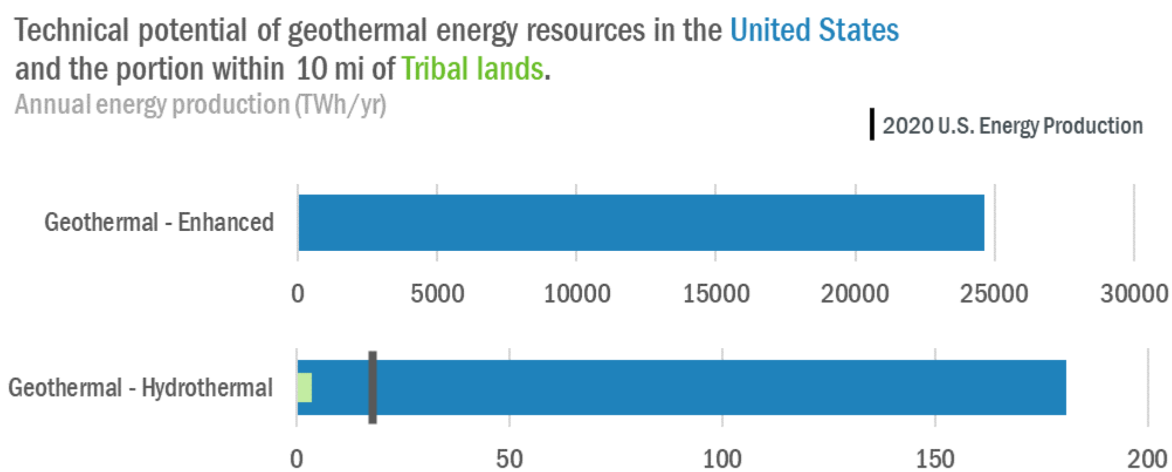

Figure 28. National energy production for geothermal energy resources

[9] Raw data underlying (Augustine, Ho, & Blair, 2019) were provided to DOE by researchers at the National Renewable Energy Laboratory for this report.

U.S. technical potential (outer bar) is from (Augustine, Ho, & Blair, 2019), technical potential within 10 mi of federally recognized Tribal lands (inner bar) is from (Milbrandt, Heimiller, & Schwabe, 2018), and 2020 energy production (line) is preliminary data from (U.S. Energy Information Administration, 2021). EGS potential on Tribal lands was not assessed.

6.2 Introduction

Geothermal energy is heat below Earth's surface, which can be used to produce continuous electricity. Like most renewable energy resources, geothermal resources require a small environmental footprint and emit little to no greenhouse gases. Hydrothermal resources consist of the naturally occurring geothermal sites used to produce electricity. The geothermal industry has generated power from hydrothermal resources in the United States since the 1970s. There remains untapped resource potential across the Western United States.

Enhanced geothermal systems are human-made geothermal reservoirs. Where the subsurface is hot, but is less permeable or contains little water, pumping fluids into wells can stimulate the formation of a geothermal reservoir capable of supporting commercial rates of energy extraction. EGS technologies are still being developed and are not yet commercially available.

6.3 Potential Assessment

6.3.1 Resource Potential

In 2008, the U.S. Geological Survey (USGS) "assessed the electric power generation potential of conventional geothermal resources in the United States." The resources identified were concentrated in Alaska, Hawaii, and the Western states. The survey inventoried 241 identified moderate-temperature (194°F–302°F) and high-temperature (greater than 302°F) sites capable of supporting geothermal development (Williams, Reed, Mariner, DeAngelo, & Galanis, 2008). Figure 29 is a map of geothermal activity in the Western United States and inventoried geothermal sites.

In 2019, NREL researchers revisited the USGS survey to update those resource potential findings given current technology developments. They estimated a resource potential of 36.5 GW is available for hydrothermal production and 5,158 GW is available for EGS production (Augustine, Ho, & Blair, 2019).[10] Because information to accurately estimate crustal temperatures on a regional basis in Alaska and Hawaii is unavailable, EGS resource assessments from (Augustine, Ho, & Blair, 2019) and (Williams, Reed, Mariner, DeAngelo, & Galanis, 2008) do not consider these states.

[10] Hydrothermal potential is the combined identified and undiscovered resource for the entire United States, including Alaska and Hawaii, found on page 16 of (Augustine, Ho, & Blair, 2019). EGS potential is the combined near-field and deep resource for the contiguous United States found on page 17 of (Augustine, Ho, & Blair, 2019)

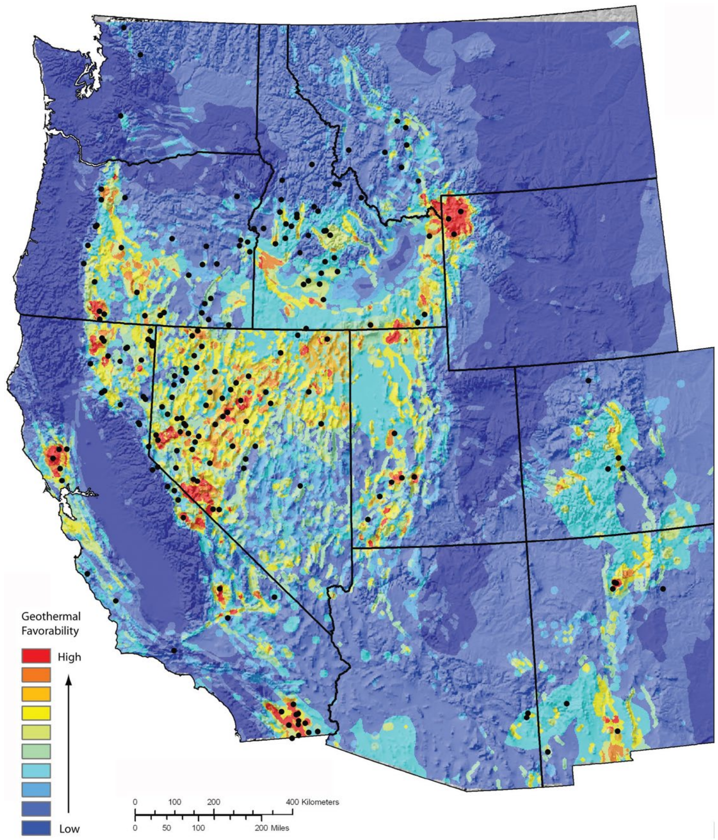

Figure 29. Map from USGS special models showing the relative favorability of occurrence for geothermal resources in the western CONUS

"Warmer" colors represent higher favorability of geothermal activity. Identified geothermal systems are represented by black dots. Image is from (Williams, Reed, Mariner, DeAngelo, & Galanis, 2008)

6.3.2 Technical Potential

NREL researchers (Augustine, Ho, & Blair, 2019) assessed the technical potential for hydrothermal and EGS resources under different scenarios for the DOE's GeoVision study (Geothermal Technologies Office, 2019). With existing technologies, hydrothermal resources have an estimated technical potential of 23.9 GW capacity and 181 TWh. The technical potential of EGS is more than 140 times that of hydrothermal with a capacity of 3,377 GW and 24,638 TWh of annual energy production.[11] The technical potential for hydrothermal and EGS energy production available to each state are shown in Figure 30 and Figure 31 respectively. When NREL researchers updated their technical potential estimates for hydrothermal technologies in 2016, they found slightly less than that calculated in 2012. The updated estimates found a technical potential of 31 GW capacity and 234 TWh annual average energy production for hydrothermal technologies (Brown, et al., 2016). They did not reassess the potential of EGS technologies. Less than 1% of this hydrothermal capacity is within 10 miles of Tribal land (Milbrandt, Heimiller, & Schwabe, 2018).

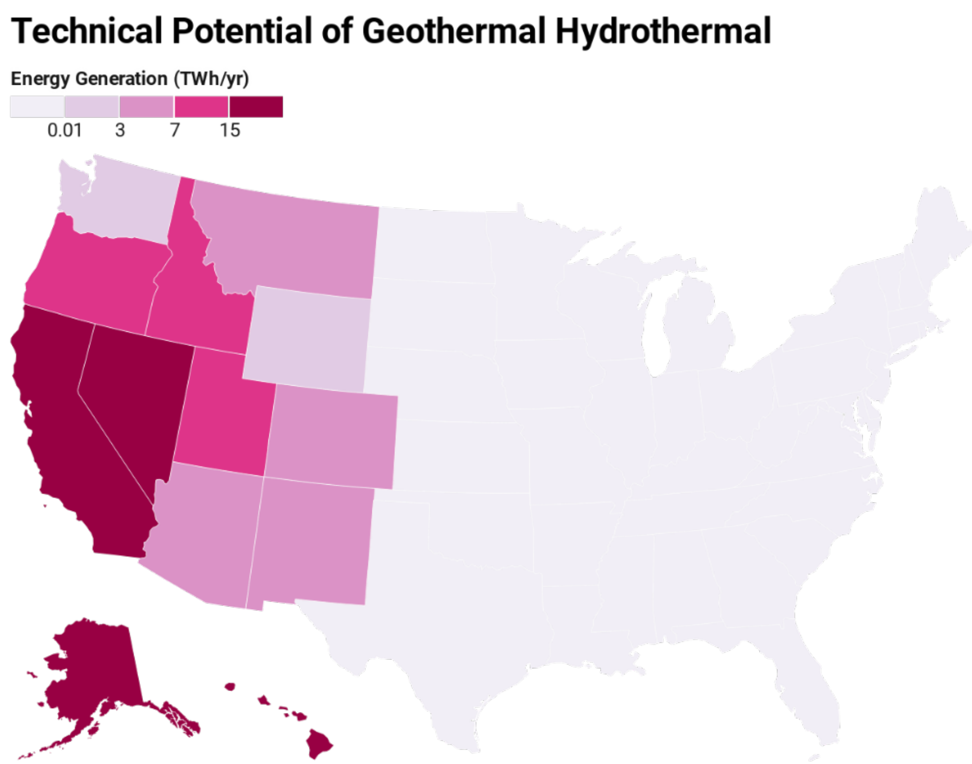

Figure 30. Annual energy production technical potential for hydrothermal geothermal energy

CONUS data are from (Augustine, Ho, & Blair, 2019). Alaska and Hawaii data are from (Lopez, et al., 2012).

[11] Raw data underlying (Augustine, Ho, & Blair, 2019) were provided to DOE by researchers at the National Renewable Energy Laboratory for this report.

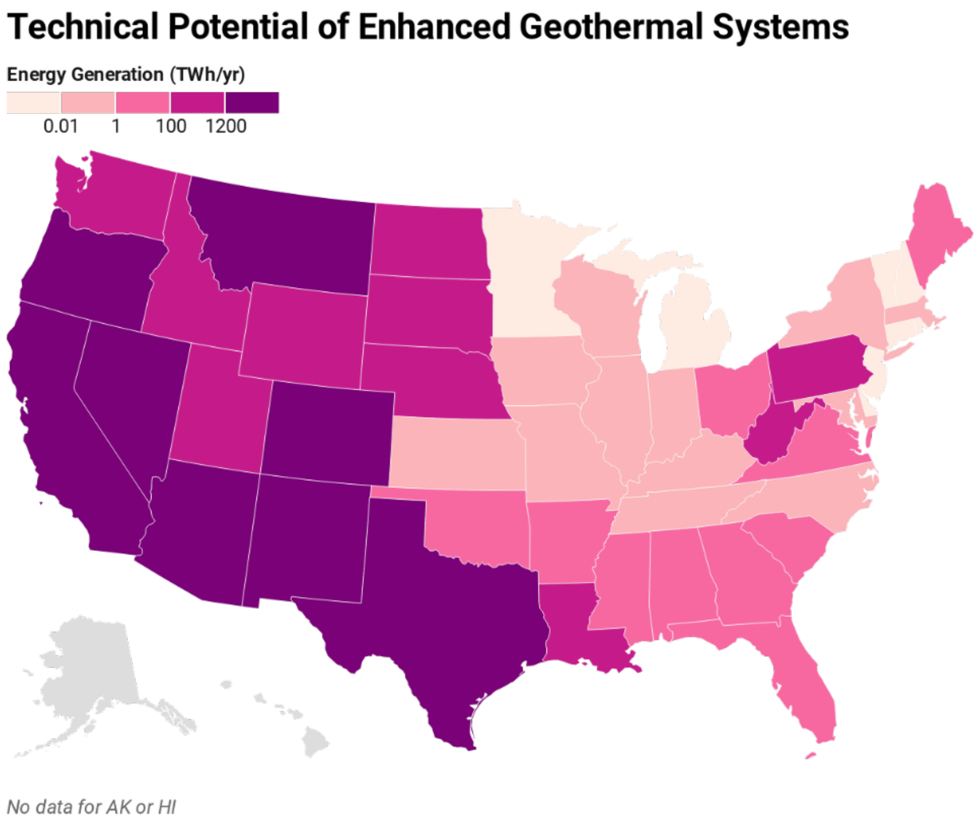

Figure 31. Annual energy production technical potential for EGS energy

Data are from (Augustine, Ho, & Blair, 2019). Potential for Alaska and Hawaii were not estimated.

6.3.3 Installed Capacity

In 2016, there were 3.8 GW of hydrothermal capacity operating in the United States, producing 15.9 TWh of energy (Augustine, Ho, & Blair, 2019). This generation remained flat through the end of the decade, and in 2020, the geothermal fleet produced 16.9 TWh of energy (U.S. Energy Information Administration, 2021). A map of all installed and in development hydrothermal resources as of 2016 is shown in Figure 32.

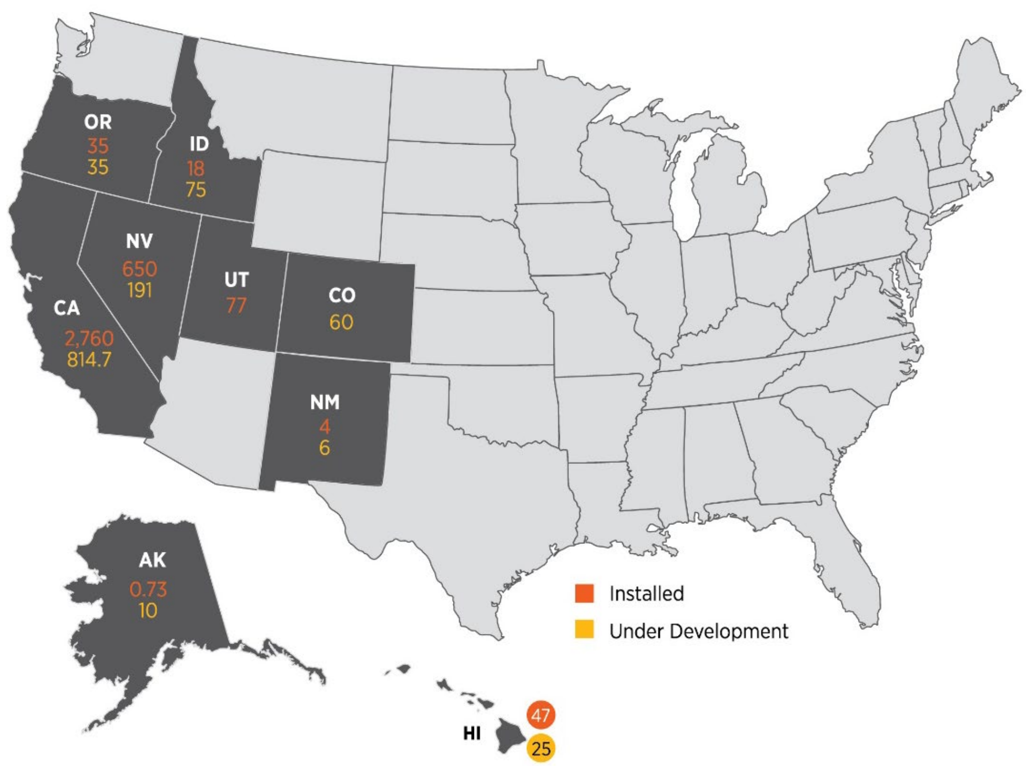

Figure 32. Current (as of 2018) and planned U.S. geothermal nameplate capacity by state in MW

Image is from (Geothermal Technologies Office, 2019).

6.4 Future Work and Needs

Additional research, development, and deployment (RD&D) is required to develop the technologies to commercialize EGS. An estimated 18.8 GW (>75%) of the total conventional hydrothermal resource technical potential in the CONUS remains undiscovered within the Basin and Range of the Western United States. To spur innovation in finding, developing, and optimizing geothermal resources, the Geothermal Technologies Office (GTO) is investing in several research portfolios. Specifically, it is:

- Leveraging the application of big data and data science through an active machine learning and geothermal applications project portfolio
- **Addressing the broader opportunity for increasing geothermal resource data fidelity:** GTO is supporting an interagency collaboration with the USGS to collect

valuable, high-resolution geophysical data across areas in Western Nevada that have high potential for undiscovered geothermal resources.

- **Supporting analysis initiatives:** Investment in R&D analysis will ensure the accurate representation of the energy costs, capabilities, and benefits required to consider geothermal for integrated resource planning activities.
- **Investing in crosscutting geothermal R&D:** GTO is investing in projects that will enable innovative research, drilling, and technology testing, and will allow researchers to identify a replicable, commercial pathway to EGS.

Though significant progress has been realized, these initiatives underscore the critical ongoing need to undertake comprehensive and updated resource assessments to drive down geothermal development risks. Such resource data can be the foundation for supporting exploration and drilling innovations through innovative data science applications, and they can increase the resource certainty needed for a host of electricity grid planning activities such as integrated resource planning. To unlock these capabilities, GTO plans to pursue partnerships with federal and nonfederal partners to capture new and comprehensive U.S. geothermal resource assessment data across the use spectrum.

7 Hydropower Energy

7.1 Summary of Hydropower Energy Potential

The U.S. hydropower sector is a mature industry, and historical deployments have already used a significant portion of the technical potential available from this resource. Studies estimate there is potential for producing 661 TWh of annual electric energy from hydropower resources in the United States[12], a value that is more than twice the existing production (U.S. Energy Information Administration, 2021). New energy potential could come from electrifying currently non-powered dams, upgrading existing hydropower facilities, or developing new low-impact projects. Table 9 shows the technical potential of hydropower energy resources, including the national capacity and energy production and the energy production within 10 miles of federally recognized Tribal lands. Figure 33 compares the annual energy production technical potential of hydropower energy resources and 2020 energy production. State-level analysis and detailed discussion of these values are found in the subsequent subsections.

Table 9. Technical Potential and Historical Generation of Hydropower Energy Resources

Resource	Potential Capacity in U.S. (GW)	Potential Energy Production in U.S. (TWh/yr)	Potential Energy Production near Tribal Lands (TWh/yr)	2020 Energy Production in U.S. (TWh/yr)
Hydropower	156	661	225	291

U.S. capacity and energy production potential are combined from (Hadjerioua, Wei, & Kao, 2012) (McManamay, et al., 2014) (U.S. Department of Energy Office of Energy Efficiency and Renewable Energy, 2014) . Energy potential that could be produced within 10 mi of federally recognized Tribal lands is from (Milbrandt, Heimiller, & Schwabe, 2018). 2020 energy production is preliminary data from (U.S. Energy Information Administration, 2021).

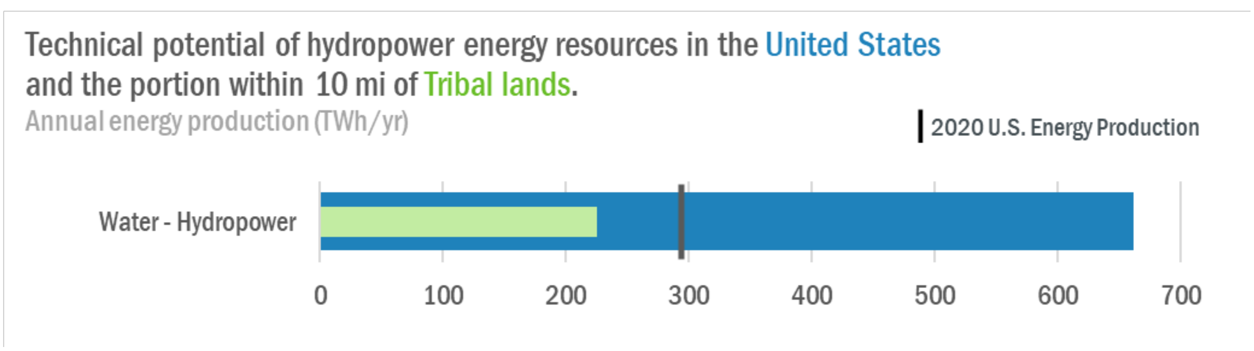

Figure 33. National energy production for hydropower energy resources

U.S. technical potential (outer bar) is combined from (Hadjerioua, Wei, & Kao, 2012) (McManamay, et al., 2014) (U.S. Department of Energy Office of Energy Efficiency and Renewable Energy, 2014), technical potential within 10 mi of federally recognized Tribal lands (inner bar) is from (Milbrandt, Heimiller, & Schwabe, 2018), and 2020 energy production (line) is preliminary data from (U.S. Energy Information Administration, 2021).

[12] Combined sum of new stream reach potential from (McManamay, et al., 2014), non-powered dams from (Hadjerioua, Wei, & Kao, 2012), and developed hydropower resources at time of publication from (U.S. Department of Energy Office of Energy Efficiency and Renewable Energy, 2014).

7.2 Introduction

Hydropower energy uses running water to make electricity without emitting greenhouse gases. Water is not reduced or consumed in the process of electricity production. Water constantly moves through a vast global cycle, evaporating from lakes and oceans, forming clouds, precipitating as rain or snow, and then flowing back down to the ocean. Because the water cycle is an endless, constantly recharging system, hydropower is considered a renewable energy source.

Hydropower technologies generate power by using a dam or diversion structure to alter the natural flow of a river or other body of water. Hydroelectric power plants can be large or small, taking advantage of water flows in municipal water facilities or irrigation ditches. Hydroelectric power plants can also be “dam-less,” with diversions or run-of-river facilities that channel part of a stream through a powerhouse before the water rejoins the main river. Hydroelectric power is a mature technology costs less than many other energy sources. Almost all U.S. states use hydropower for electricity, and some get most of their electricity from hydropower.

7.3 Potential Assessment

7.3.1 Technical Potential

The many means to develop hydroelectric power in the United States include electrifying and upgrading existing water infrastructure and developing brand new hydropower facilities. Oak Ridge National Laboratory has inventoried the resource potential of both existing infrastructure and new stream development.

In 2012, Oak Ridge National Laboratory considered the resource potential of powering non-powered dams. Researchers inventoried more than 54,000 of the 80,000 non-powered dams in the United States and identified a total of 12 GW capacity that could be suitable for powering; this additional hydropower capacity would produce 45 TWh of annual energy, increasing the existing hydropower fleet at that time by approximately 15% (Hadjerioua, Wei, & Kao, 2012). Figure 34 shows the location and relative size of non-powered dams in the United States. Most of the existing non-powered dam potential is in the eastern half of the United States.

In 2014, Oak Ridge National Laboratory conducted an inventory of national streams to calculate the resource potential of new stream-reach development. That inventory identifies and characterizes stream reaches with high energy densities, focusing specifically on undeveloped stream reaches (McManamay, et al., 2014). Importantly, the study combines “the energy potential of stream reaches with information related to natural ecological systems; sensitive species; areas of social and cultural importance; and policy, management, and legal constraints” (McManamay, et al., 2014). The total U.S. resource potential of new stream-reach development is estimated at 65.5 GW capacity, with 347 TWh annual energy production (McManamay, et al., 2014). Figure 35 shows the resource potential of new stream-reach development for each subbasin of the nation’s watersheds.

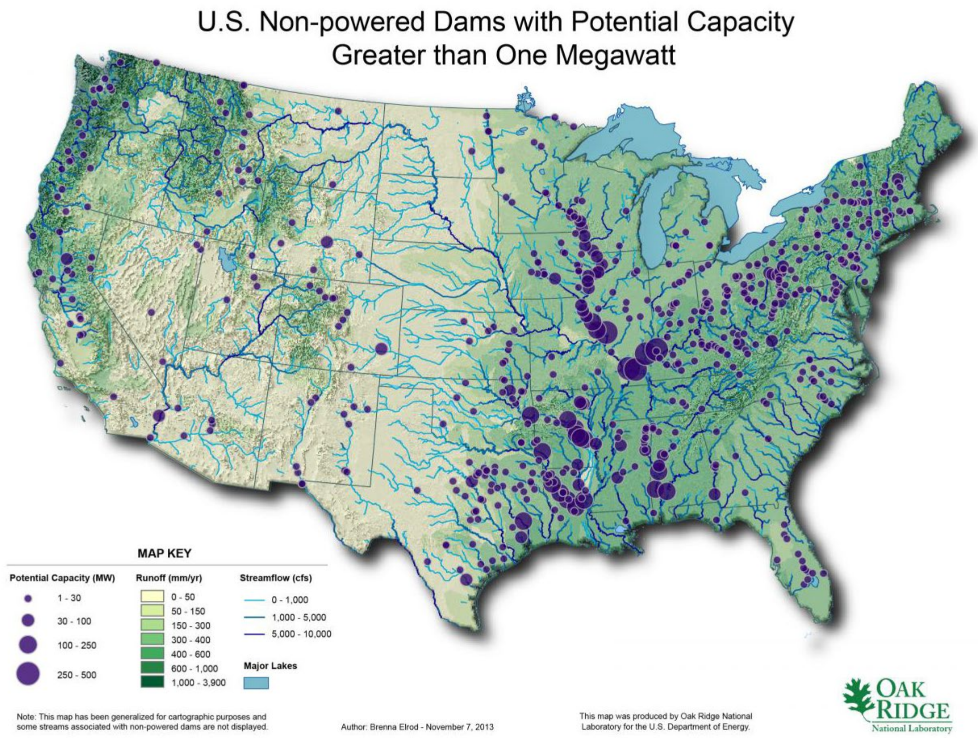

Figure 34. Map of U.S. non-powered dams with potential capacity greater than 1 MW

Image is from (Hadjerioua, Wei, & Kao, 2012).

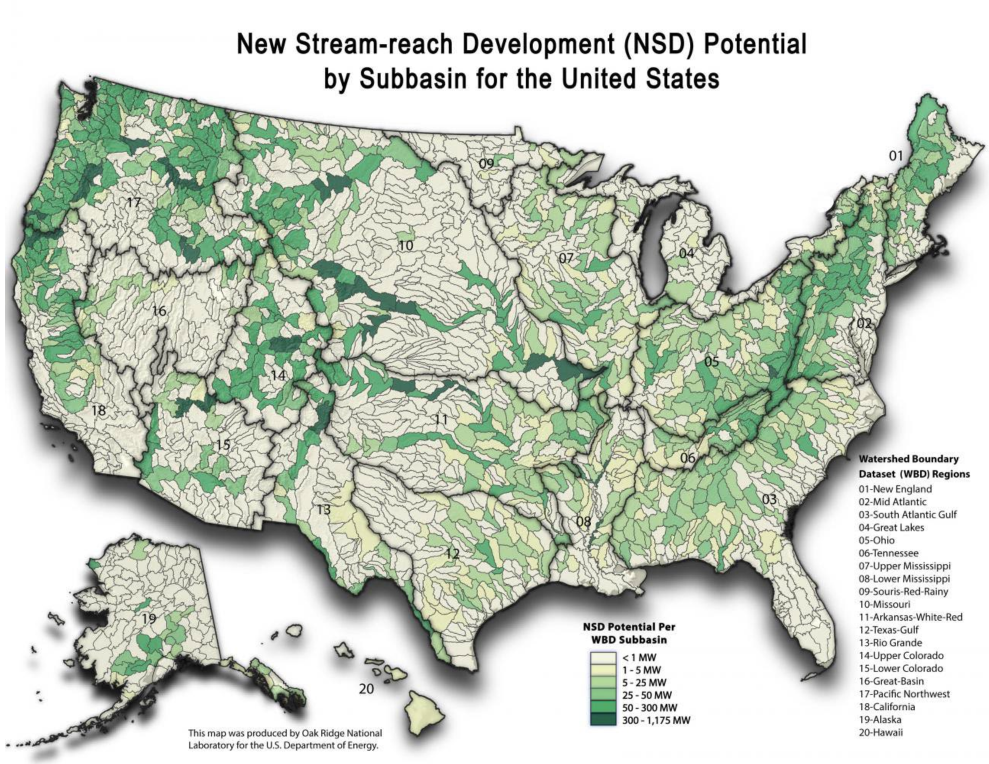

Figure 35. Map of new stream-reach development resource potential by subbasin for the United States

Image is from (McManamay, et al., 2014).

Combining the additional 45 TWh/yr technical potential available from powering non-powered dams (Hadjerioua, Wei, & Kao, 2012), 347 TWh/yr new stream-reach development (McManamay, et al., 2014), and the 269 TWh/yr hydropower power that was already developed at the time of the resource assessment studies from (U.S. Department of Energy Office of Energy Efficiency and Renewable Energy, 2014) results in the total absolute technical potential available in the United States. A total technical potential of 661 TWh of hydropower energy is available in the United States.

7.3.2 Installed Capacity

Oak Ridge National Laboratory maintains a continuously updated database of existing hydropower facilities. At the end of 2019, the U.S. hydropower fleet comprised 2,270 plants with a total capacity of 80.25 GW (Uria-Martinez, Johnson, & Shan, 2021). Installed hydropower capacity in each state as of 2016 is shown in Figure 37 (Water Power Technologies Office, 2016). The Northwest produces approximately 50% of all hydropower in the United States (Uria-Martinez, Johnson, & O'Connor, 2018).

Despite significant year-to-year fluctuations in regional hydropower generation that correlates with hydrologic conditions, the annual U.S. hydropower generation volume remained stable between 250 TWh and 275 TWh between 2003 and 2016 (Uria-Martinez, Johnson, & O'Connor, 2018). In 2020, hydropower contributed 291 TWh to the nation’s electricity mix (U.S. Energy Information Administration, 2021).

Though hydropower is a mature technology, more than 217 new hydropower projects were in the development pipeline as of 2019 (Uria-Martinez, Johnson, & Shan, 2021), including projects powering currently non-powered dams, developing new stream reaches, powering water conduits used for other purposes, and adding capacity at already operational plants. Figure 38 shows the location and relative size of all new projects.

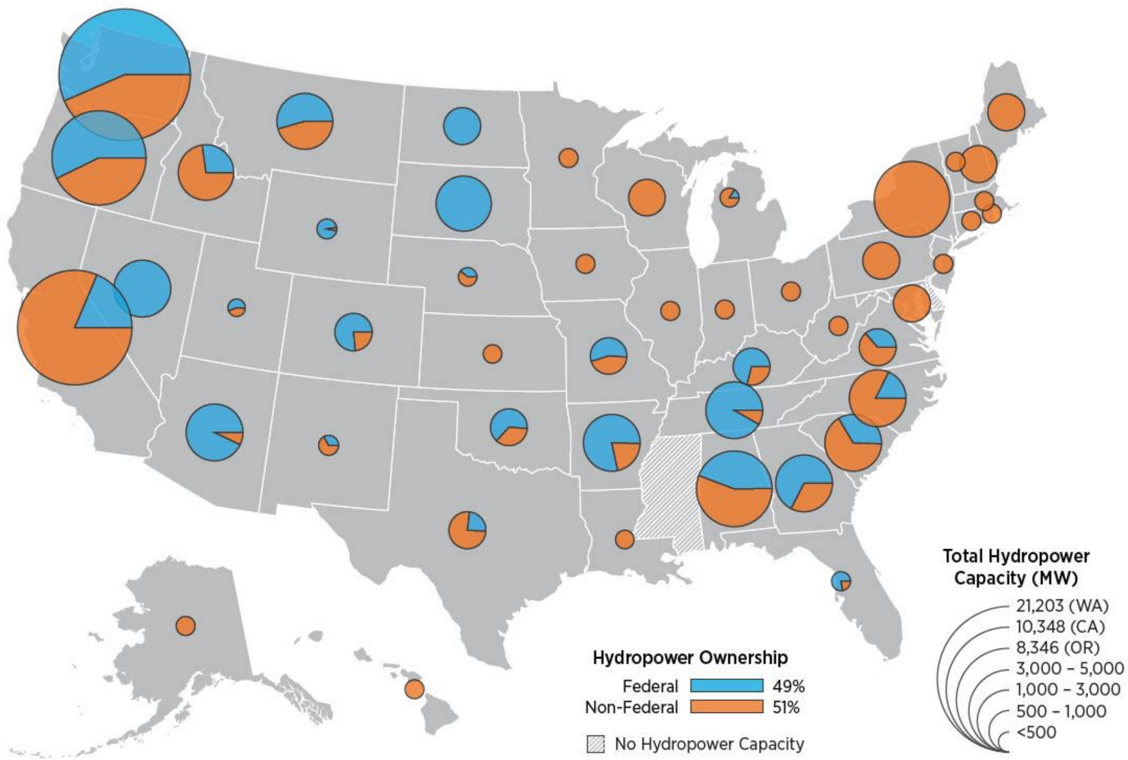

Figure 36. Existing hydropower fleet capacity in 2016 by state and ownership of facility

Image is from (Water Power Technologies Office, 2016).

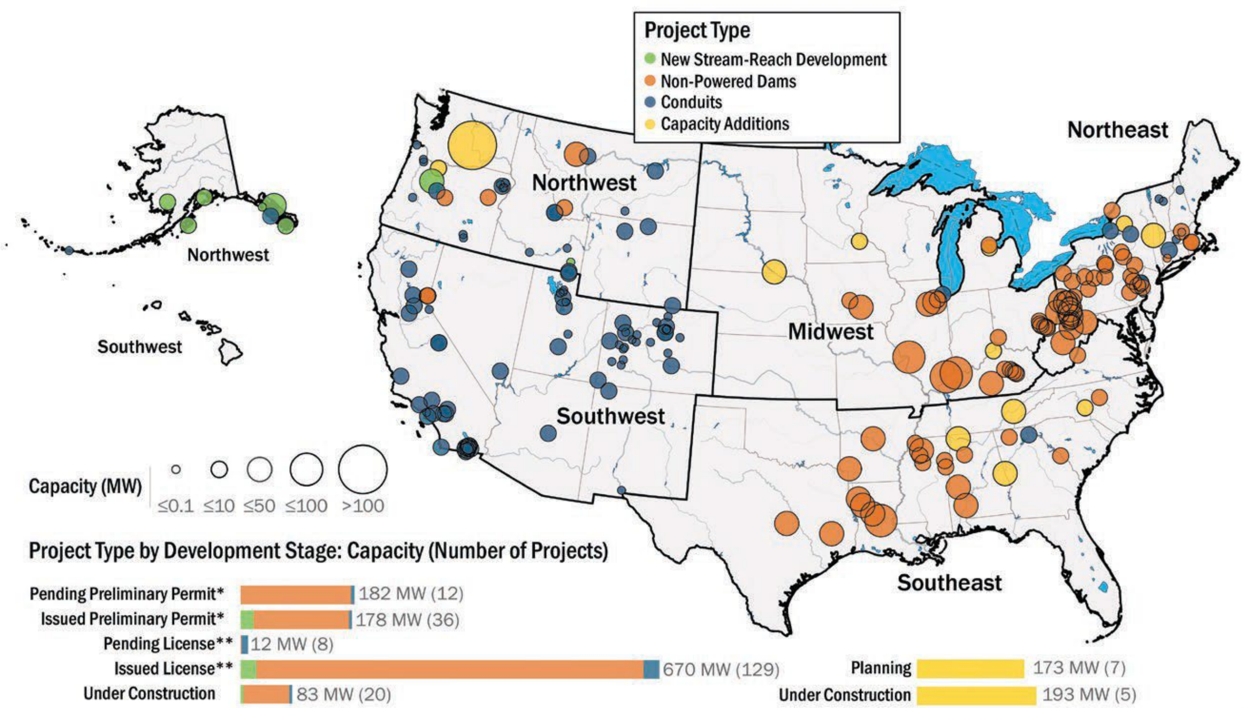

Figure 37. Hydropower project development pipeline by project type, region, size, and development stage as of the end of 2019

Image is from (Uria-Martinez, Johnson, & Shan, 2021).

7.4 Future Work and Needs

The Water Power Technologies Office (WPTO) has identified several actions to optimize hydropower's continued contribution to a clean, reliable, low-carbon, domestic energy generation portfolio while also ensuring the Nation's natural resources are adequately protected or conserved. These actions are organized into five key areas:

- **Innovations for Low-Impact Hydropower Growth:** Technology innovation can enable the growth of additional hydropower capacity and generation as an economically competitive source of renewable energy in four resource categories: (1) development in new stream reaches, (2) powering of currently nonpowered dams, (3) the addition of generation technology to existing irrigation canals and other water conduits, (4) and upgrades at existing hydropower plants.
- **Grid Reliability, Resilience, and Integration:** Rapid changes in the U.S. electricity system, including changes in generation mix as well as markets and policy, have created new needs for storage, flexibility, and other grid services that hydropower and pumped-storage hydropower are well suited to provide.
- **Fleet Modernization, Maintenance, and Cybersecurity:** The existing hydropower and pumped-storage fleets are aging (the average age of facilities is over 55 years), and new innovations are needed to ensure these critical assets can continue to safely and cost-effectively operate and provide value into the future.
- **Environmental and Hydrologic Systems Science:** Though hydropower has tremendous value to the power system as a flexible, renewable resource, its long-term value depends on maintaining a high level of environmental performance across the fleet. The DOE Hydropower Program develops new technologies, tools, and data to better understand and improve the environmental performance of hydropower facilities.
- **Data Access and Analytics:** As a technology-neutral, national research agency with access to some of the most advanced computing, data management, and analytics in the nation, DOE is well suited to work closely with other agencies and stakeholders to improve the data landscape for important hydropower and river-related information.

8 Summary

This report summarizes the results of nearly 30 national renewable energy resource assessments performed by the U.S. national laboratories since 2012. The following are highlights from the report:

- The United States is a resource-rich country with abundant renewable energy resources. Every region of the country has access to multiple renewable energy resources. The available renewable resource is 100 times that of the Nation's annual electricity need.
- Over 9% of the nationally available renewable energy resource is found within 10 miles of federally recognized Tribal lands.
- Solar, wind and geothermal are the most abundant renewable energy resources nationwide. Ocean, biomass, and hydropower energy resources have important roles to play in each region where they are found.
- There is a large, untapped technical potential to convert gross renewable resources into electricity. In 2020, the United States used only 0.2% of the total available renewable energy potential available for electricity production.
- Both an expansion of current technology deployment and research activities will enable increased access to the Nation's renewable energy resource potential.

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