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Renewable Energy in the US Power Sector, the Other Revolution

July 2018

REI – Renewable Energy Institute

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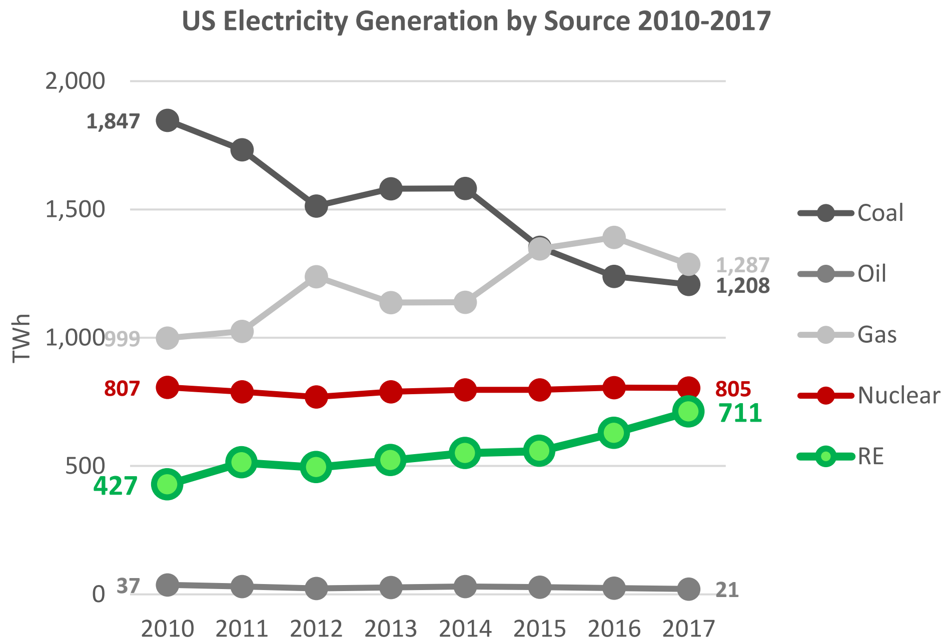
EXECUTIVE SUMMARY

Following the shale gas revolution, another revolution is unfolding in the United States (US) power sector. Already the second of the 21st century. This second, or "other" revolution, is driven by a massive deployment of wind and solar power. Between 2010 and 2017, essentially thanks to these two technologies, electricity generation from renewable energy (RE) increased roughly as much as that from gas power; both over +280 terawatt-hours.



Note: To improve readability others, which are relatively negligible, are not included in this chart
Source: US EIA, [Annual Electricity Report 2016] and [Monthly Electricity Report February 2018]

Progresses have, however, been uneven across the country. Among key States, California is a leader for solar power with 16% of the State electricity generation coming from solar. And Texas is a leader for wind power with 15% of the State electricity generation from wind. The West North Central region of the Midwestern States; North Dakota, South Dakota, Nebraska, Kansas, Minnesota, and Iowa, as well as Oklahoma, Nevada, or Hawaii have also demonstrated strong leadership. That is not the case of Southeastern States (e.g. Florida, Alabama, Georgia), the East North Central region of the Midwestern States (Wisconsin, Illinois, Indiana, Ohio, and Michigan) and the Northeastern State of Pennsylvania, where progresses have been either moderate or limited.

This unequal deployment of RE across the US is due to the fact that the country can be defined as a "patchwork" of natural resources, electricity system reform, supportive policies, and electrical grids. All of which are impacting RE penetration.

RE expansion comes with a number of benefits and challenges:

From an economic point of view, thanks to technology cost reduction, now cost competitive wind and solar power; at around \$40/megawatt-hour and \$55/megawatt-hour, respectively, are the promise of affordable electricity rates for businesses and households.

From an environmental point of view, RE fast expansion enables an accelerated decarbonization of the US power sector; -24% of carbon dioxide emissions since 2000, with all economic and health associated benefits.

At the same time, variability of wind and solar power is often described as a challenge from a grid integration perspective. Yet, both wind and solar curtailment rates are currently low (well below 5%) thanks to various solutions; interstate electricity trading, flexible operations of conventional gas and hydro power plants, grid expansion, battery storage, and demand response.

Regarding market integration, close to zero marginal cost wind and solar power are pushing out of the market uneconomic power plants, particularly coal and nuclear power stations, a challenge some power generating companies have failed to address. These developments have led to a number of bankruptcies, among which the most striking ones are those of Energy Future Holdings, FirstEnergy, and GenOn.

The last key challenge is to ensure that increasing demand, either compulsory or voluntary, for RE is properly met. The issue here lies in the difference of procurement possibilities at the State level with customers sometimes facing difficulties to get renewable electricity, essentially when electricity system reform has not taken place. A number of solutions exist such as unbundled renewable energy certificates for example. Overall the situation is improving as RE becomes more widely available with States progressing towards fulfilment of their renewable portfolio standards and utilities offering more options for customers to purchase RE electricity.

All these advances are taking place thanks to smart people quick to take advantage of new opportunities in all sectors of the American economy:

Forward-thinking power generators and suppliers. Companies like NextEra Energy and Berkshire Hathaway Energy now have more than 14 gigawatts and 8 gigawatts, respectively, wind and solar power capacity in their generating portfolios. And many retailers are introducing innovative business models with various offers around RE and solutions for their integration; electricity rate-based mechanisms to procure RE, solar utility programs, and customers' electricity consumption optimization tools and services.

Businesses are increasingly committing to RE driven by sustainability initiatives and cost-competitiveness of wind and solar power. Many US businesses are targeting 100% renewable electricity, and some of them have already reached this target; Apple, Google, Microsoft, Starbucks, and Wells Fargo for example. And as of 16 May 2018, about 12 gigawatts of corporate RE deals had been announced in the US since 2013.

Finally, local political authorities and social pioneers are also making a big difference. States and cities set ambitious targets and put in place enabling policies. For instance, the renewable portfolio standard of Hawaii aims for 100% RE electricity by 2045, and those of California and New York for 50% by 2030. The cities of Minneapolis, Pittsburgh, San Francisco, Salt Lake City, or Seattle are all targeting 100% RE electricity. And people either collectively or individually are also leading the change at the community or household levels by procuring renewable electricity and/or generating their own green electricity. Electricity generation from residential solar photovoltaic – only – reached almost 14 terawatt-hours in 2017. That is approximately twice more than a couple of years ago, and almost three times more than the electricity supplied from the US latest new build nuclear reactor Watts Bar 2 (capacity of about 1.2 gigawatt) in 2017.

INTRODUCTION

The United States (US) has been the world's largest single economy for at least over a half-century. And it is the world's second largest electricity consumer and generator today (behind China).

As such its economic and electrical systems have often served as models for many countries around the world. Particularly in developed economies after World War II, including Japan and many European countries.

As decades have passed, the influence of the US has remained strong in Japan where political leaders and decision-makers in the industry follow with great attention key developments in the US economy and energy sector.

This report aims at further enriching the Japanese energy debate by providing information on an under-reported major paradigm shift in the US power sector; the "other revolution," which is characterized by a massive deployment of cost-competitive wind and solar power across the US.

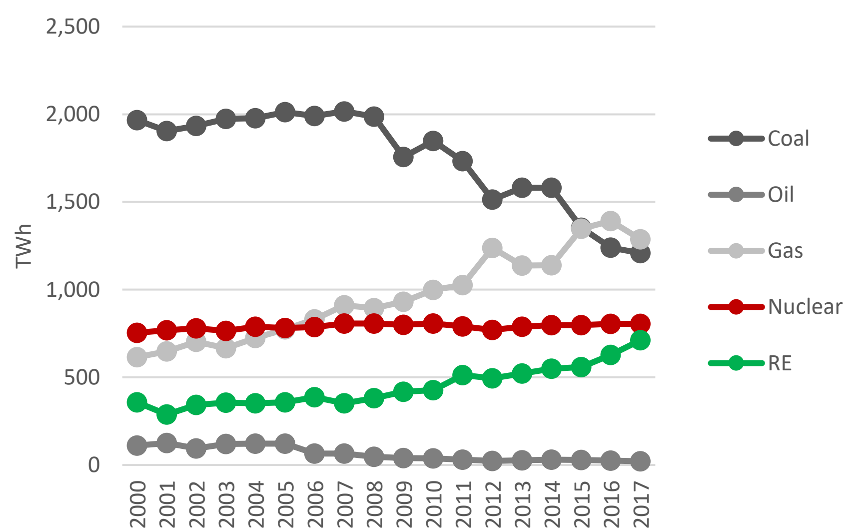
I KEY DEVELOPMENTS IN THE US POWER SECTOR, WITH A FOCUS ON RE

1 National level; the beginning of the "other revolution"

Since around 2010, the US power sector is undergoing a new revolution, the second already since the beginning of this century.

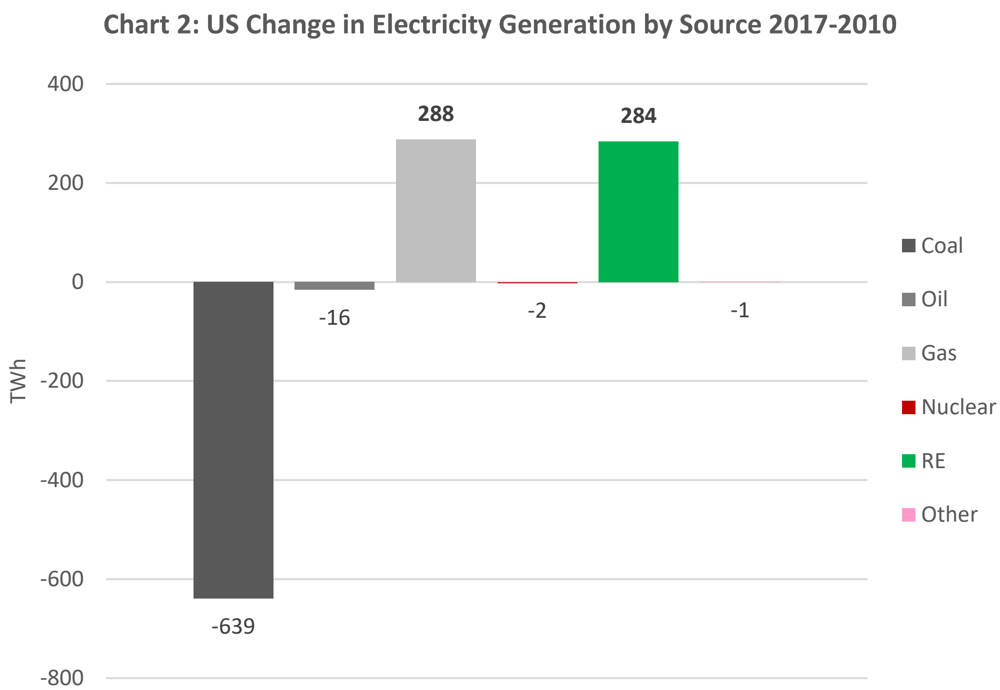
Started in the 2000s, the "unconventional gas revolution" (or "shale gas revolution" as most of new gas production comes from shale gas and tight oil plays) has first significantly transformed the US electric power sector. New extraction techniques; drilling horizontal wells and hydraulic fracturing, have made abundant resources of relatively cheap gas (average cost of $3-$5/million British thermal units – on an annual basis since 2009) available for electricity generation.[1] As a result, gas eventually became the first source for electricity generation in the US in 2016 (Chart 1).

Chart 1: US Electricity Generation by Source 2000-2017



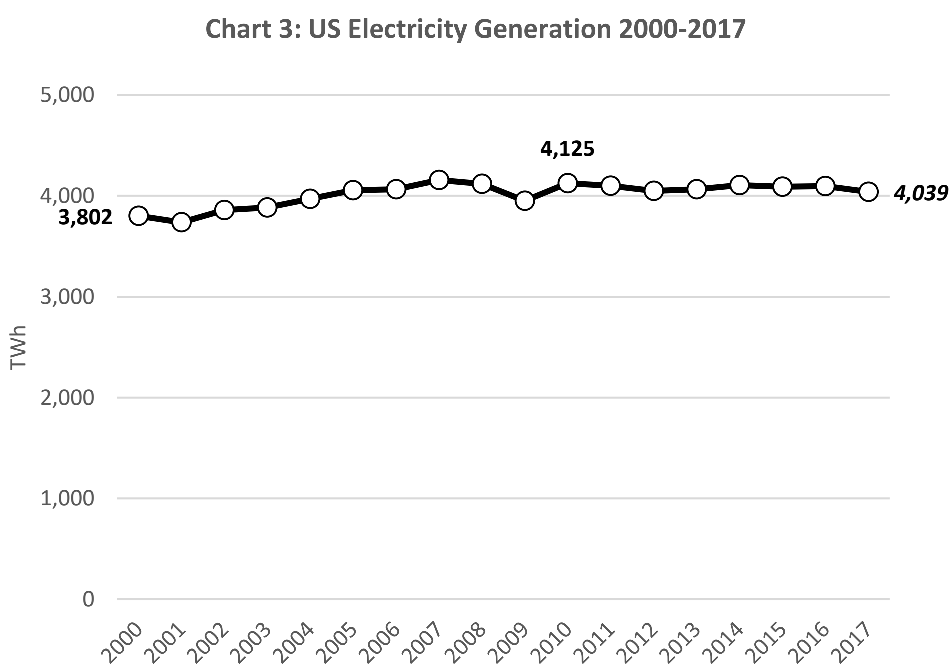
Note: To improve readability others, which are relatively negligible, are not included in this chart
Source: US EIA, Annual Electricity Report 2010-2016 and Monthly Electricity Report February 2018

In the shadow of this first revolution, another much untold revolution began around 2010, characterized by the massive deployment of new renewable energy (RE) power. Indeed, while electricity generation from gas increased by 288 terawatt-hours (TWh) between 2010 and 2017, electricity generation from RE increased by 284TWh in the same period – roughly the same amount (Chart 2 on next page).



Source: US EIA, [Annual Electricity Report 2016] and [Monthly Electricity Report February 2018]

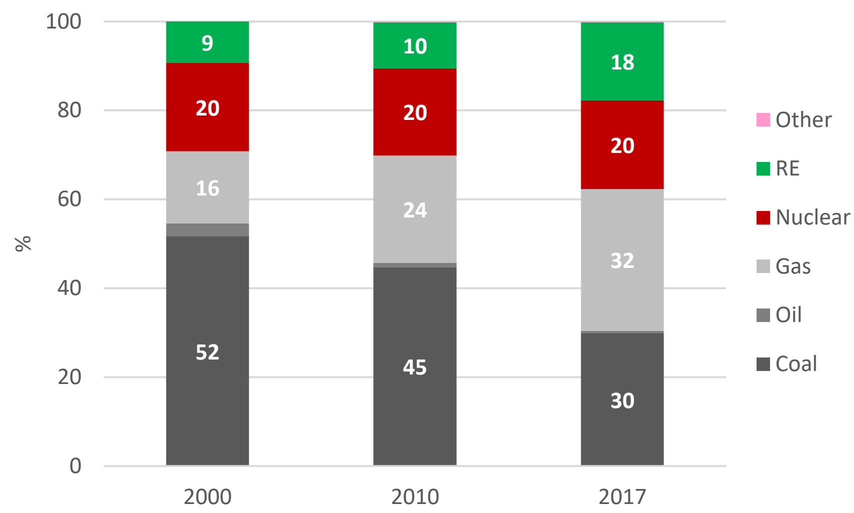
Combined with stagnating electricity generation (Chart 3), these developments have delivered a severe blow to coal power especially. Though not visible on Chart 2 nuclear power is also suffering from these developments, from an economic perspective notably (discussed in "II 4 Market integration of close to zero marginal cost RE").



Source: US EIA, [Annual Electricity Report 2010-2016] and [Monthly Electricity Report February 2018]

Consequently, the US electricity mix has quite evolved since 2000. Coal no longer accounts for the majority of US electricity generation, but "only" 30%. Gas share doubled from 16% to 32%. RE share also doubled from 9% to 18%, but with progresses essentially concentrated after 2010, and is now within striking distance of nuclear power that remained around 20% (Chart 4).

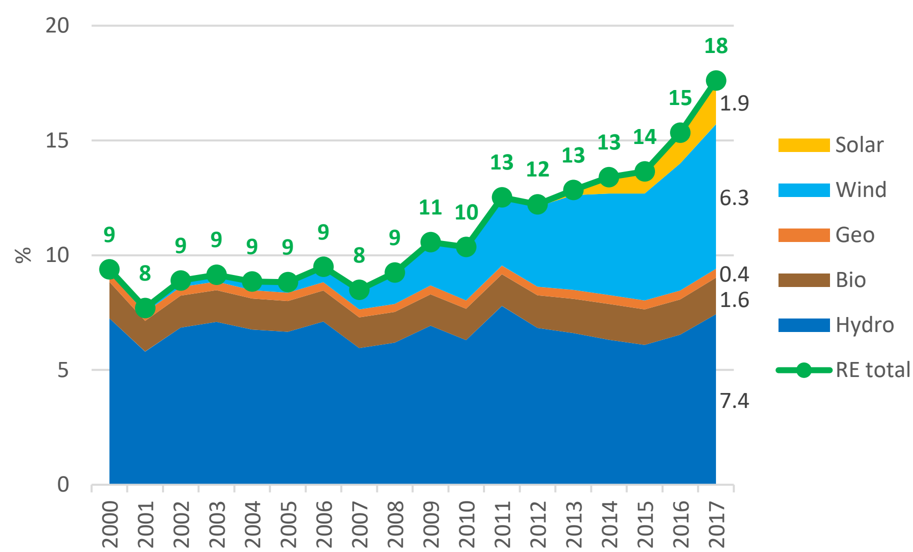
Chart 4: US Share in Electricity Generation by Source 2000, 2010, and 2017



Source: US EIA, [Annual Electricity Report 2016]() and [Monthly Electricity Report February 2018]()

Among RE, growth in electricity generation has mainly come from wind, and more recently, solar power. Whereas their respective shares in electricity generation were only 2.3% and 0.0% in 2010, they have now reached 6.3% and 1.9% (Chart 5).

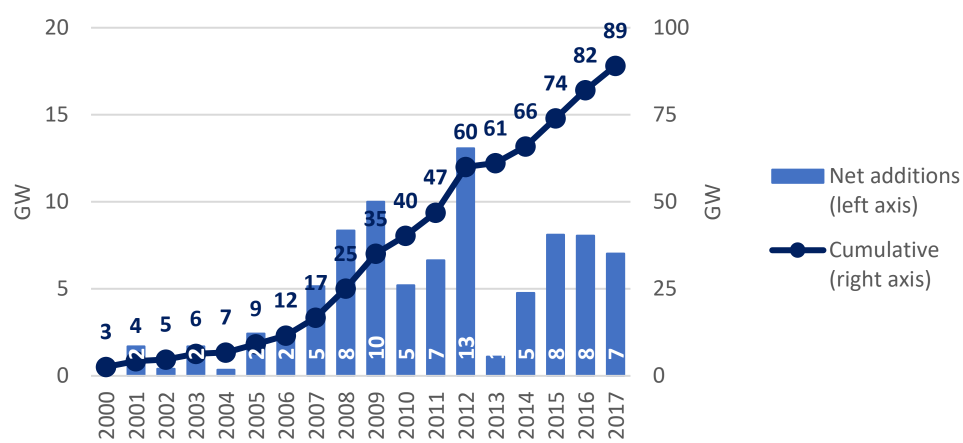
Chart 5: US RE Share in Electricity Generation by Source 2000-2017



Source: US EIA, [Annual Electricity Report 2016]() and [Monthly Electricity Report February 2018]()

These remarkable progresses result from the significant additions of capacity for both technologies. Indeed, wind power capacity reached almost 90 gigawatts (GW) in 2017, more than a doubling since 2010 (Chart 6).

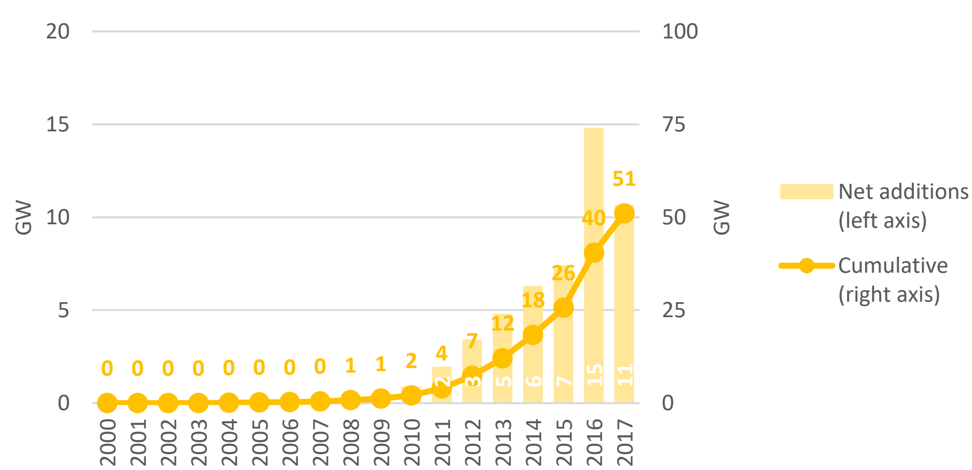
Chart 6: US Installed Wind Capacity 2000-2017



Source: GWEC, Global Wind Report 2010 and 2017

And solar power capacity over 50GW, from close to nothing at the beginning of the decade (Chart 7).

Chart 7: US Installed Solar PV Capacity 2000-2017

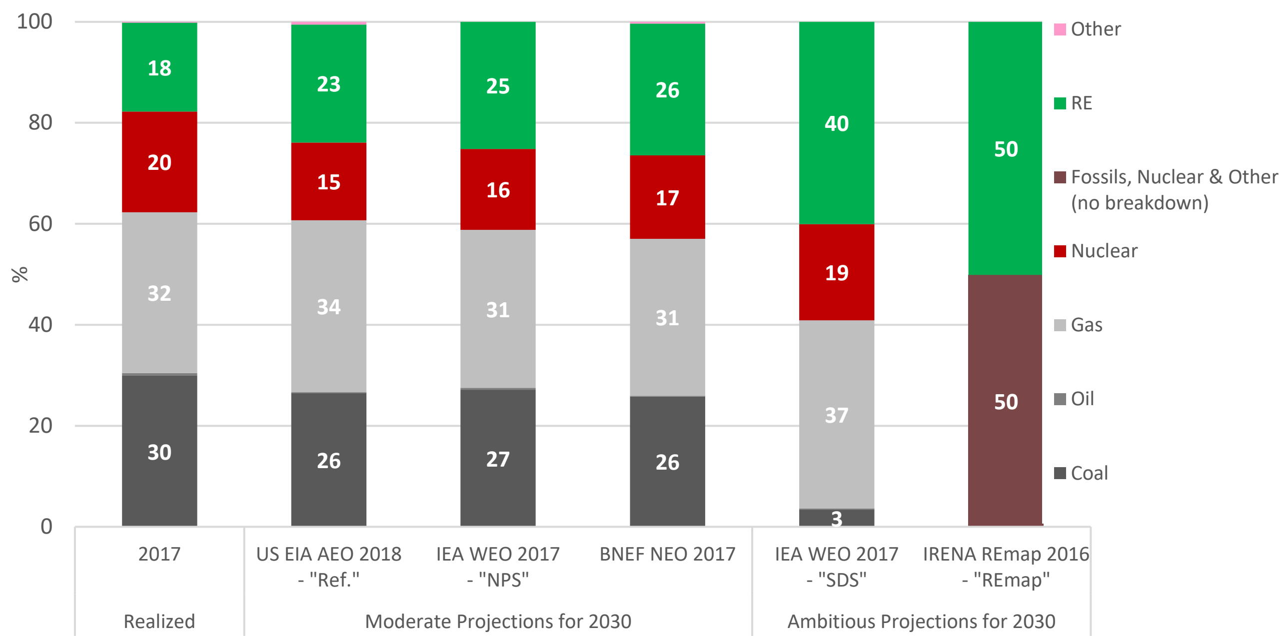


Source: IEA PVPS, Trends in Photovoltaic Applications 2017 and Snapshot of Global Photovoltaic Markets 2018

And roughly another 20GW of wind power and 10GW of utility-scale solar are expected to be connected to the US grid within the next three years.[2] Additional progresses are thus yet to come in the short-term.

In the medium-term – by 2030, according to a number of forecasts from various organizations, RE share in US electricity generation could reach around 25% in moderate scenarios, and between 40% and 50% in ambitious scenarios, compared with 18% in 2017 (Chart 8 on next page).

Chart 8: US Electricity Generation Mix Projections for 2030



Notes: "Ref." means "Reference," "NPS" means "New Policies Scenario," and "SDS" means "Sustainable Development Scenario"
Sources: US EIA Monthly Electricity Report February 2018 and Annual Energy Outlook 2018, IEA, World Energy Outlook 2017, BNEF, New Energy Outlook 2017, and IRENA, Roadmap for a Renewable Energy Future 2016

For comparison purposes Table 1 summarizes key electricity indicators for US and Japan in 2017.

Table 1: US and Japan Key Electricity Indicators Comparison 2017

Indicators	US	Japan
Electricity generation (TWh)	4,039	1,020
Electricity generation mix (%)		
Coal	29.9	29.3
Oil	0.5	6.9
Gas	31.9	39.4
Nuclear	19.9	2.9
Hydro	7.4	7.8
Bio	1.6	1.6
Geo	0.4	0.2
Wind	6.3	1.0
Solar	1.9	5.4
Other	0.2	5.6
Wind power cumulative capacity (GW)	89	3
Solar PV power cumulative capacity (GW)	51	49

Sources: US electricity generation and mix; US EIA, Monthly Electricity Report February 2018, Japan electricity generation and mix; REI, Quarterly Trends of Total Electricity Production (accessed 24 April 2018), for wind power cumulative capacity; GWEC, Global Wind Report 2017, and for solar power cumulative capacity; IEA PVPS, Snapshot of Global Photovoltaic Markets 2018

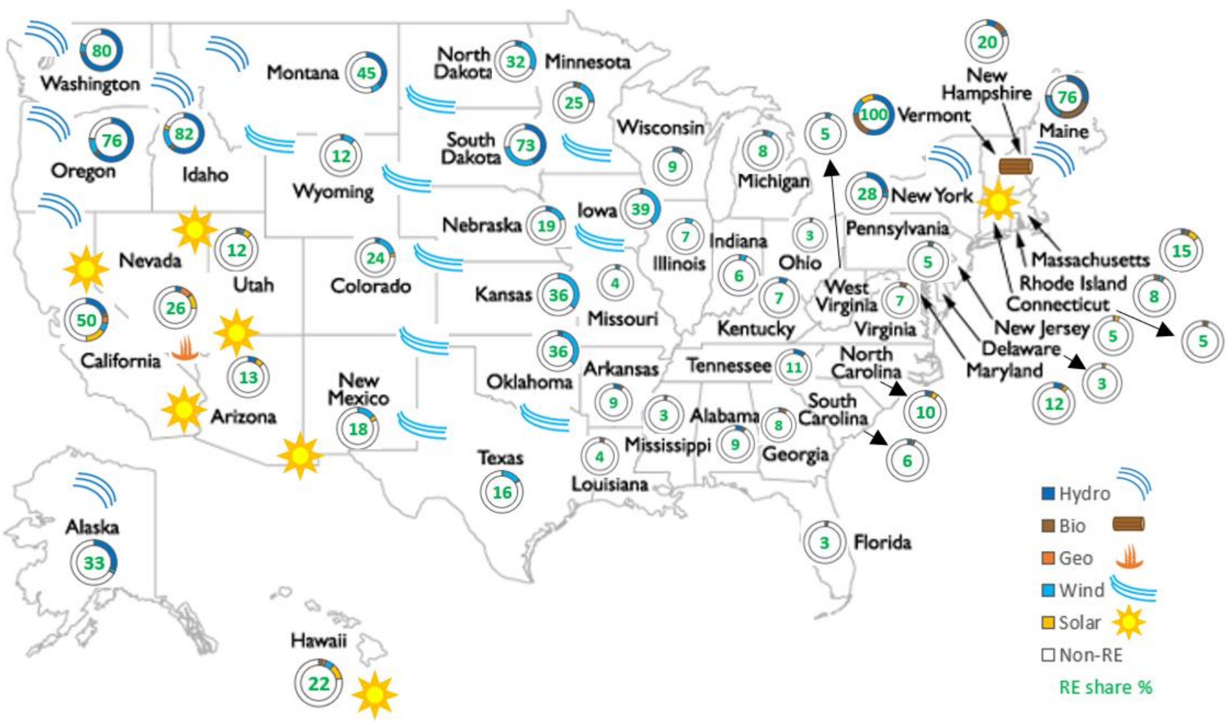
2 Regional penetration of RE; unevenly distributed progresses

Though progresses at the national level have been rather impressive, achievements differ a lot from a State to another, with leaders and laggards.

In 2017, in 13 of the 50 US States RE accounted for more than 30% of electricity generation. At the same time, in 21 States RE accounted for less than 10% of electricity generation. This clearly indicates that deployment of RE is not taking place at the same pace everywhere across the country.

Map 1 shows the share of RE in electricity generation for each State as well as the contribution of each RE source (hydro, bio, geo, wind, and solar) and highlights the main RE technology deployed in different areas of the country.

Map 1: US States Status of RE Deployment 2017



Source: Created by REI based on US EIA, Monthly Electricity Report February 2018

Hydro accounts for a large (30-70%) share of electricity generation in the Northwest (Washington, Oregon, Idaho, Montana), Northeast (Maine and Vermont), and Alaska.

Bio share in electricity generation is significant (10-25%) in the Northeast (Maine, New Hampshire, and Vermont).

Geo represents a not negligible (5-10%) share of electricity generation in Nevada and California.

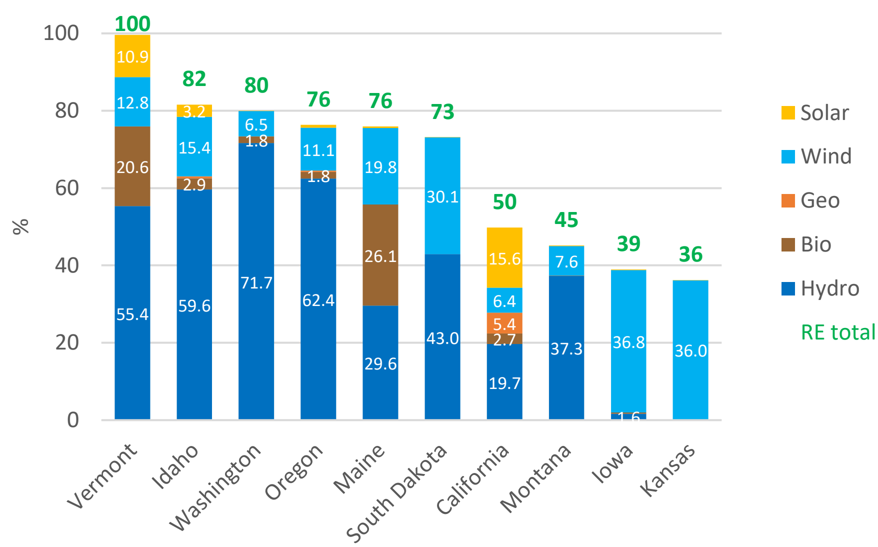
Wind plays an important (15-35%) role in the electricity generation of all the West North Central region of the Midwestern States (North Dakota, South Dakota, Nebraska, Kansas, Minnesota, and Iowa) – with the exception of Missouri, and in Oklahoma and Texas.

And solar starts to be significantly (5-15%) deployed in the Southwest (California, Nevada, Arizona, Utah), a few Northeastern States (Vermont and Massachusetts), and Hawaii.

So far, progress in the Southeastern States (e.g. Florida, Alabama, Georgia), the East North Central region of the Midwestern States (Wisconsin, Illinois, Indiana, Ohio, and Michigan) and the Northeastern State of Pennsylvania have been either moderate or limited.

In five US States RE accounted for over 75% of electricity generation in 2017; Vermont, Idaho, Washington, Oregon, and Maine (Chart 9). That is usually primarily thanks to hydro, in combination with wind and/or bio. Vermont, the smallest State in terms of electricity generation (2TWh)[a], is the undisputed leader with almost 100% of electricity generated in the State coming from RE with important contribution from all sources except geo. With 50% of electricity generation from RE, California, the 3rd largest State in terms of total electricity generation in the country (217TWh), ranks 7.[b]

Chart 9: Top 10 RE Share in Electricity Generation by State 2017

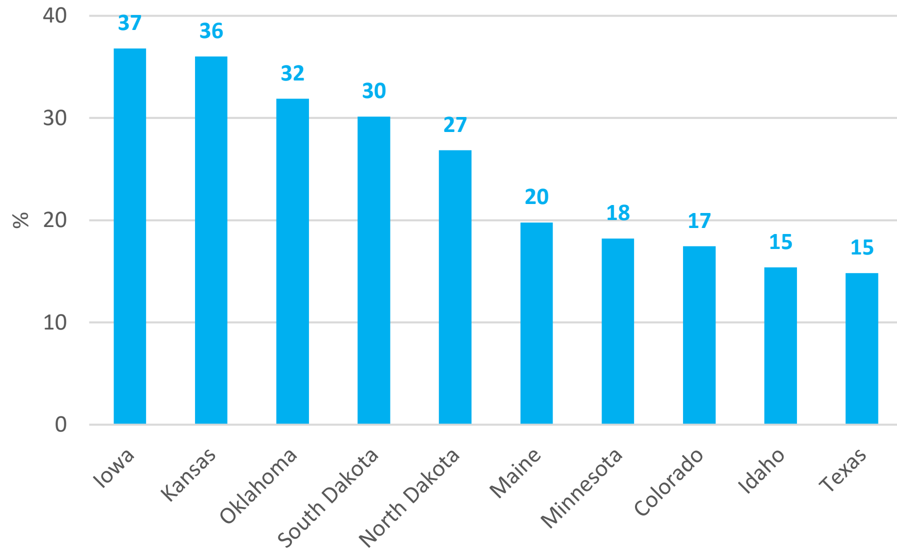


Source: US EIA, Monthly Electricity Report February 2018

States which have been the most aggressive in deploying wind power are 4 Midwestern States (Iowa, Kansas, South Dakota, and North Dakota) and Oklahoma. In these 5 States wind share in electricity generation reached over 25% in 2017 (Chart 10 on next page). Texas, by very far the largest State in terms of total electricity generation in the country (453TWh) – more than twice that of California, closes the top 10 with wind accounting for 15% of the State electricity generation.

[a] Complete ranking of States total electricity generation is available in Appendix A "Ranking of US States Total Electricity Generation 2017" on page 57 of the report.
[b] This 50% RE share in electricity generation is not to be compared with California renewable portfolio standard (RPS) which requires electric utilities, among others, to increase procurement from eligible RE resources to 50% of total procurement by 2030. First, because eligible RE resources under RPS do no include large hydro. Second, because RPS covers retail sales (i.e. consumption) not generation, and California is a relatively large importer of electricity; about a quarter of its needs on average).

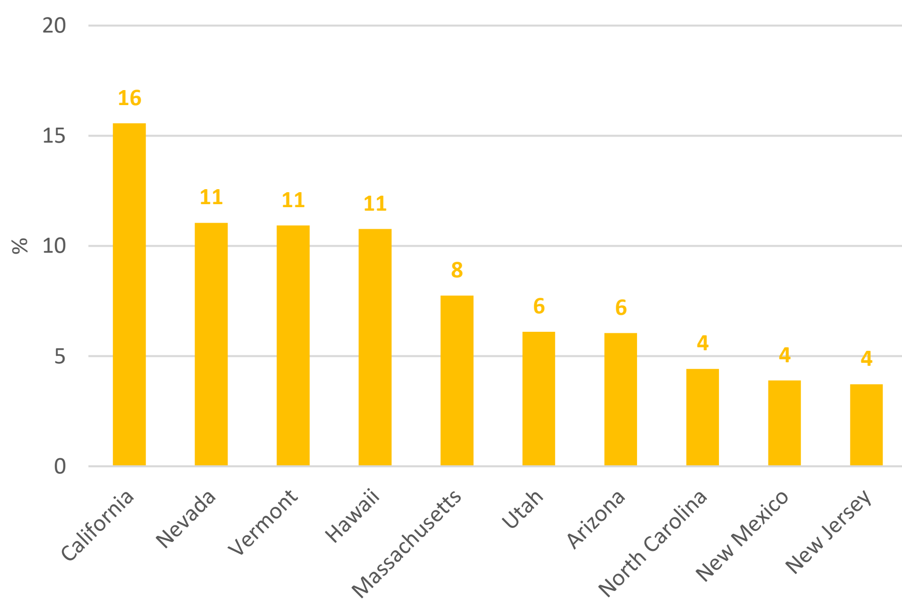
Chart 10: Top 10 Wind Share in Electricity Generation by State 2017



Source: US EIA, Monthly Electricity Report February 2018

As for solar, California leads the way with a share of about 16% in electricity generation (Chart 11). Follows a group of 3 States from different geographical areas; Nevada (Southwest), Vermont (Northeast), and Hawaii (in the middle of the Pacific Ocean) all around 11%. This demonstrates the great potential for solar to be deployed under very different conditions.

Chart 11: Top 10 Solar Share in Electricity Generation by State 2017



Source: US EIA, Monthly Electricity Report February 2018

3 The US as a "patchwork"

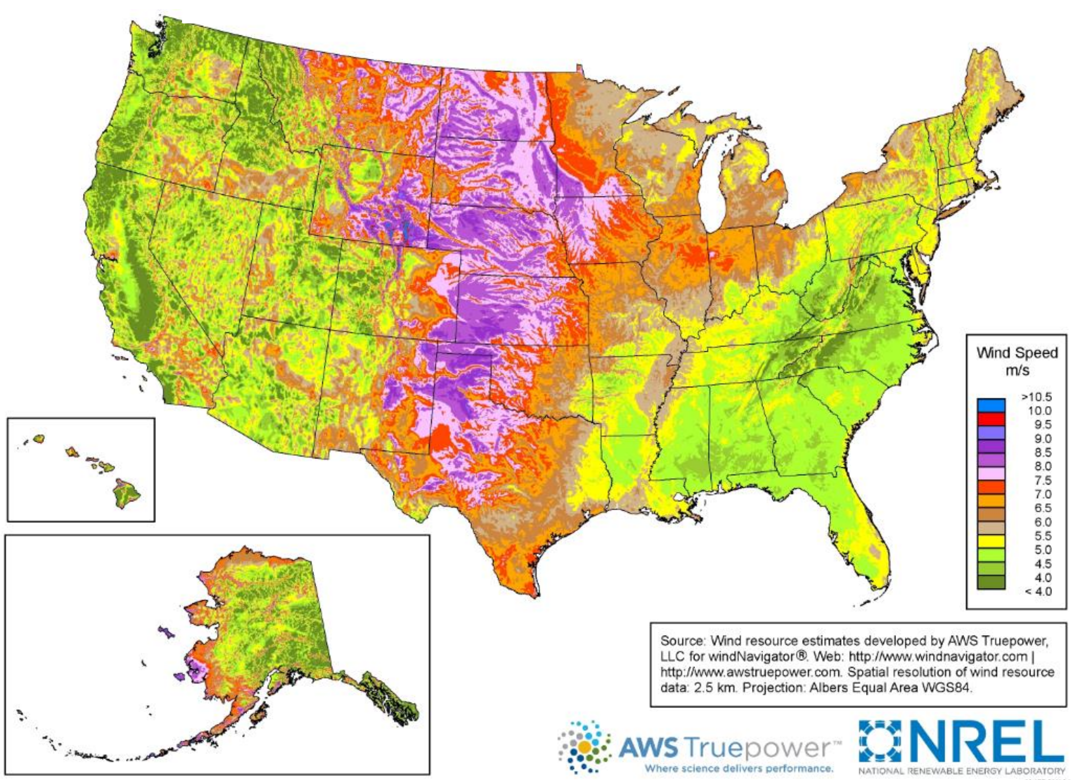
Progresses in RE deployment across the US is unequal. That is because RE penetration depends on multiple factors; potential of natural resources, electricity system reform (re-regulation, unbundling and power markets), supportive policies, and interconnection of electrical grids. And in that regard the US is very much a patchwork.[c]

- In this section, the factors impacting the deployment of onshore wind and solar photovoltaic (PV) only will be focused on as these two technologies have been the two major drivers of the "other revolution." -

Among the key factors that influence deployment of RE the most obvious one may be the potential of natural resources.

As for wind resources, Map 2 indicates that Midwestern States as well as Oklahoma and Texas are blessed with particularly good wind resources. That certainly helped the massive development of wind power in these areas. Yet, this does not seem to always be sufficient as the case of Missouri lets suggest it. Though this State has good wind resources only 2% of its electricity generation came from wind power in 2017.

Map 2: US Annual Average Wind Speed at 80 m



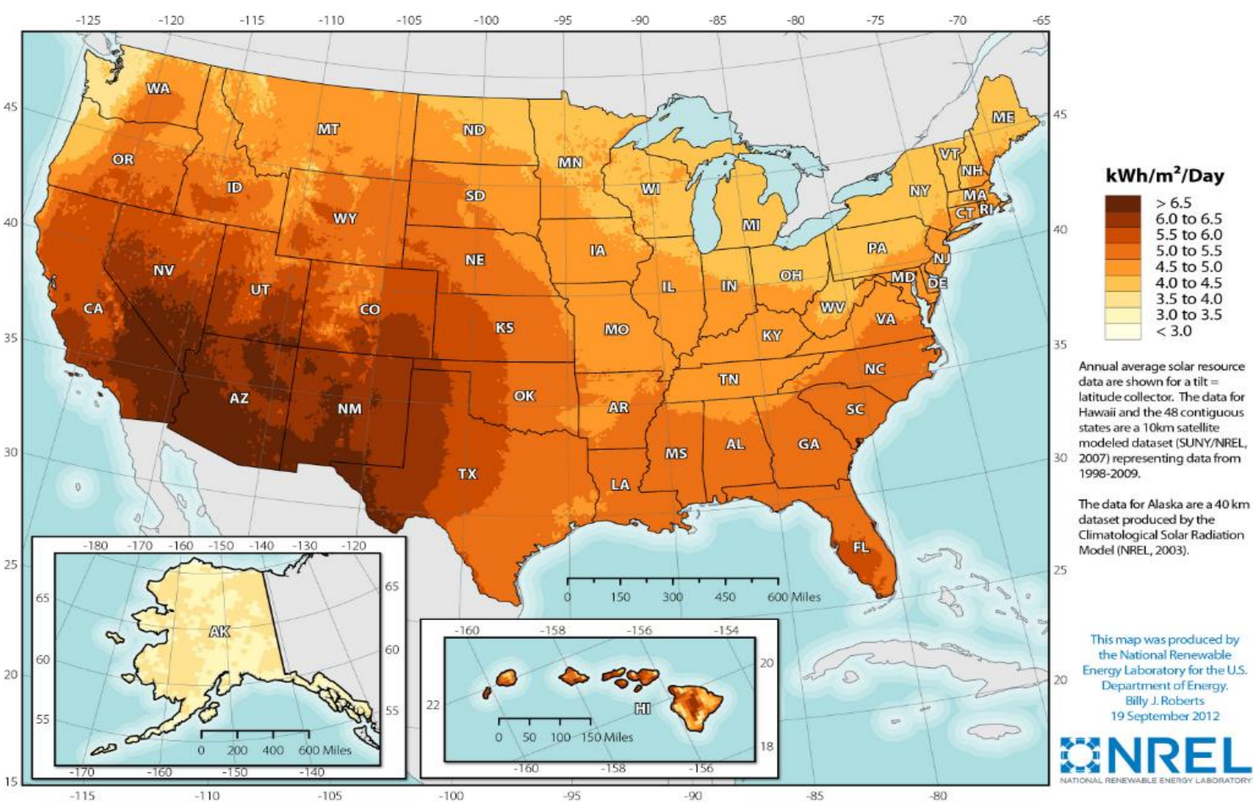
Source: NREL, United States – Annual Average Wind Speed at 80 m (accessed 27 March 2018)

As for solar PV, Map 3 (on next page) indicates that Southern States, and especially Southwestern States, have particularly good solar PV resources. That can help to explain why States like California and Nevada

[c] Throughout this section a number of maps are provided some of which use abbreviations of US States names. Appendix B "US States Abbreviation List" on page 58 of the report aims at facilitating the reading of these maps.

have the highest shares of electricity generation from solar in the country. However, once again good resources are not always synonym of significant deployment. A very good illustration of that point is Florida, which solar PV resources are much better than those of Northeastern States, but painfully failed at generating 1% of its electricity from solar in 2017 while Massachusetts and New Jersey managed to reach shares of 8% and 4%, respectively.

Map 3: US Solar PV Resource



Source: NREL, Photovoltaic Solar Resource of the United States (accessed 27 March 2018)

These observations lead to the conclusion that good potential of natural resources is an advantage to massively deploy wind and solar, but it is not sufficient.

Another factor that may impact the deployment of wind and solar is electricity system reform (ESR), or the re-regulation and unbundling of vertically integrated electric utilities (i.e. power companies in Japan and Europe), which provide generation, transmission, distribution, and supply of electricity to customers at regulated rates and with administratively determined profits.

Historically, in the case of the US, utilities can be defined as large firms owning and/or operating facilities used for production, transportation, and delivery of electricity, gas, or water to general public. A typical example is Pacific Gas and Electric (PG&E) in California which has been a combined electric and gas utility for over a century.[3]

Incumbent integrated electric utilities may slow down the entrance of new entrants at the generation and supply levels because of their overwhelming market size, or by not providing fair grid access to new capacity and/or not offering competitive electricity prices to new suppliers.

In this regard, important efforts started in the US from the 1970s (Timeline). First with the Public Utility Regulatory Policies Act (PURPA) passed by the Congress in 1978, which introduced competition to the vertically integrated electric utilities by requiring utilities to purchase power from small independent electricity generators at the "avoided cost" the utility would spend to generate the electricity itself.[4] Then with the Energy Policy Act of 1992 allowing the Federal Energy Regulatory Commission (FERC) to approve "exempt wholesale generators" to go into the generation business and sell electricity at competitive prices. This act also authorized FERC to order transmission owners (vertically integrated electric utilities) to provide transmission service to new entrants. In 1996, through Order No. 888, FERC required transmission owners under its jurisdiction to provide open-access (i.e. all similarly situated parties are charged the same rate and provided service under the same terms and conditions) transmission to the interstate transmission grid. And in 1999, it issued Order No. 2000 promoting voluntary participation in regional transmission operators (RTOs)/ independent system operators (ISOs).[5]

Timeline: US Electricity System Reform Key Stages

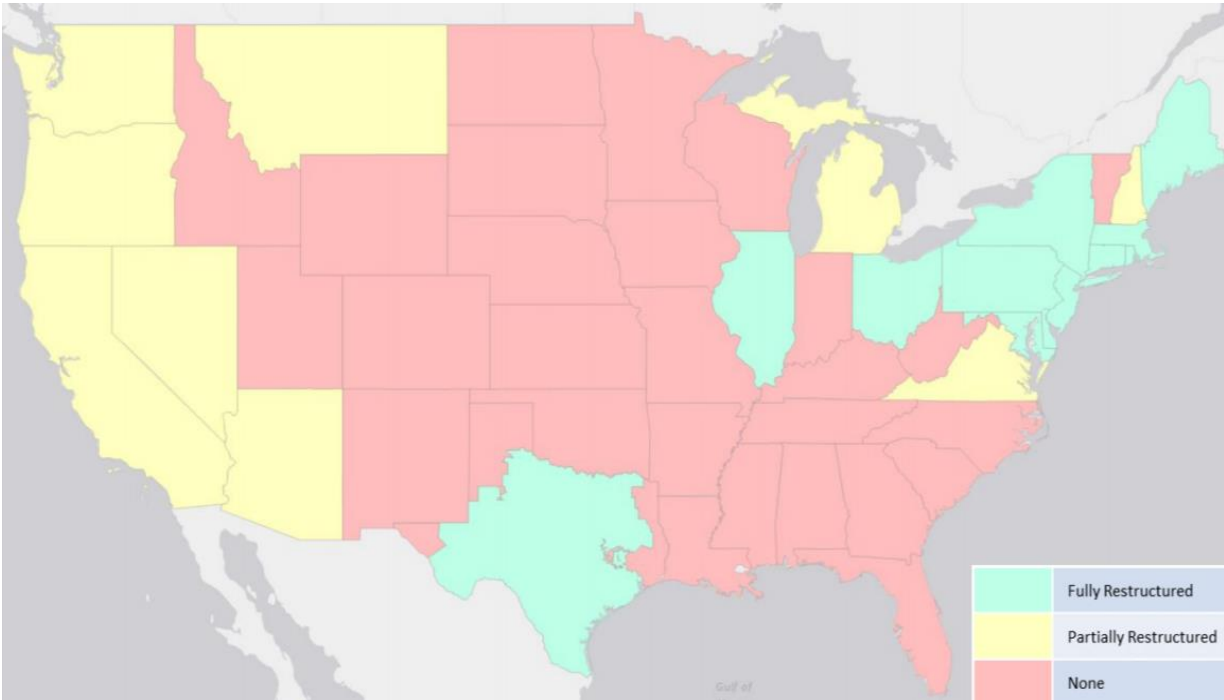
1978	**Congress - Public Utility Regulatory Policies Act (PURPA)** *- Introduction of competition to vertically integrated electric utilities*
1992	**Energy Policy Act** *- FERC allowed to approve exempt wholesale generators* *- FERC authorized to order transmission owners to provide transmission service*
1996	**FERC - Order No. 888** *- Open-access requirement*
1999	**FERC - Order No. 2000** *- Promotion of voluntary participation in RTOs/ISOs*

Source: Created by REI based on US DOE, Staff Report to the Secretary on Electricity Markets and Reliability August 2017

Between 1998 and 2006, 23 States made changes to require their vertically integrated electric utilities to divest some or all of their generating assets and thus allow competition. At the same time retail competition was introduced. This wave of re-regulation did not sweep the entire country though. Indeed, ESR efforts have so far been conducted in States accounting for 53% of total US retail electricity sales "only." (Map 4 on next page).[6]

Among large State electricity consumers whereas Texas, California, Ohio, and New York have either fully or partially gone through re-regulation, Florida, Georgia, and North Carolina did not progress.

Map 4: Re-Regulation by State as of May 2017



Note: "Partially restructured" means States that have divested some generation and/or allowed a portion of customers to choose their energy provider

Source: US DOE, [Staff Report to the Secretary on Electricity Markets and Reliability August 2017]

In addition, following these reforms there are now seven RTOs/ISOs in the US (Map 5 on next page).[d] These transmission system operators (TSOs) are independent from competitive segments (generation and supply) interests. They do not own any physical assets. They operate the transmission system operations, ensure non-discriminatory access to the transmission grid, and run electricity markets. They are thus key actors for the transparent and efficient functioning of electricity markets in their balancing area.

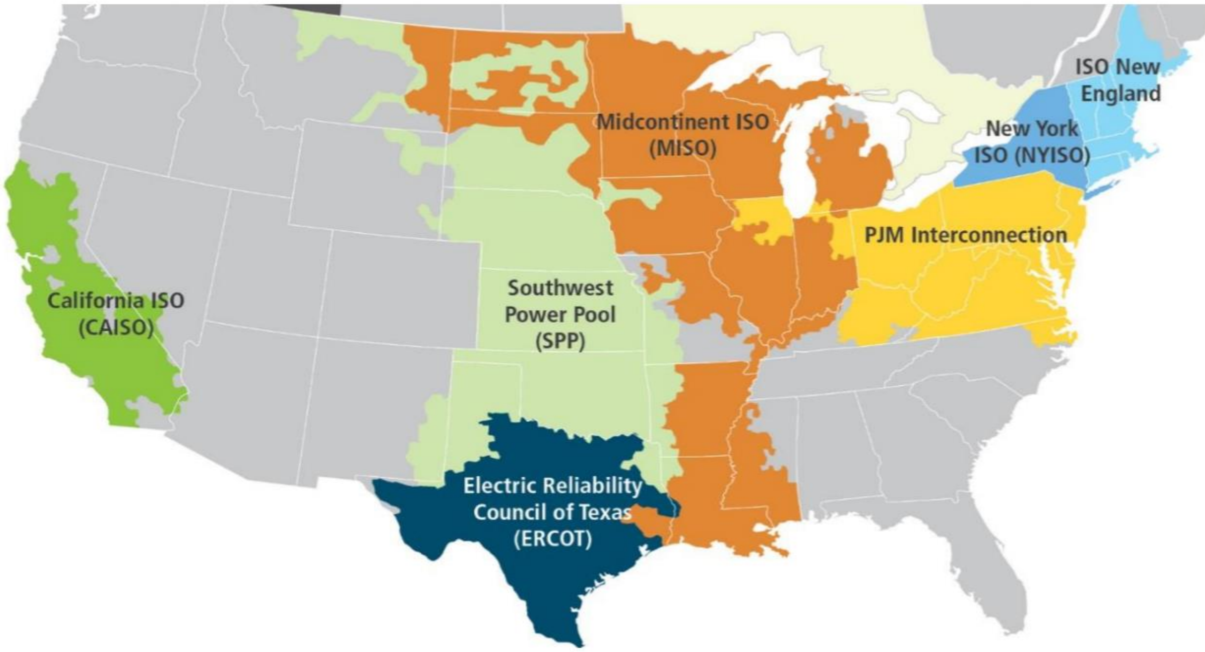
This model of TSO also exists in Europe. In Great Britain for instance, with the ISOs Scottish Hydro Electric Transmission and Scottish Power Transmission.

Japan has opted for the independent transmission operator (ITO) model in which a TSO owns the grid assets and belongs to a vertically integrated company, with special rules to guarantee its independence. This model has also been chosen in France for example.

Neither the ITO nor the ownership unbundling model, implying the appointment of the network owner as the system operator and its independence from any generation and supply interests, exist in the US.

[d] The difference between RTOs and ISOs is largely semantic and will not be discussed in this report as it is not its main focus.

Map 5: The Seven RTOs or ISOs in the US



Source: US DOE, Staff Report to the Secretary on Electricity Markets and Reliability August 2017

From this information about the progresses of ESR across the US it is possible to provide additional observations. In Texas where ESR has been aggressively pursued significant RE growth took place (essentially in wind power until now). There are States such as California and the West North Central region of Midwestern States where ESR has been moderate and dynamic RE developments have been realized. At the same time there are States such as Pennsylvania and Illinois where ESR has been pursued aggressively and RE growth has been moderate. And finally, there are States where ESR did not take place such as Colorado and Florida with diametrically opposed results in terms of RE expansion; Colorado is among the leaders for wind power and Florida is a laggard for wind and solar despite, again, interesting potential resources for the latter.

Table 2 (on next page) summarizes the impact of ESR on major utilities in different key US States.

Table 2: US Electricity System Reform Summary with Illustrative Utility Examples

ESR Status	Generation	Transmission	Distribution	Supply	State
Fully re-regulated	TXU				Texas (before)
	Luminant (2007)	Oncor (2007) / ISO: ERCOT (1996)		TXU Energy (2002)	Texas (after)
Partially re-regulated (1)	PG&E				California (before)
	PG&E (forced divesture)	PG&E / ISO: CAISO (1998)		PG&E	California (after)
Partially re-regulated (2)	Virginia Electric and Power				Virginia (before)
	Dominion Generation (2007)	Dominion Virginia Power (2007) / RTO: PJM (2005)		Dominion Virginia Power (2007)	Virginia (after)
Partially re-regulated (3)	Portland General Electric				Oregon (before)
	Portland General Electric	Portland General Electric		Portland General Electric	Oregon (after)
Not re-regulated	Florida Power & Light				Florida

Status of the market:

Competitive Limited competition Regulated

Note: In case of unbundling, ownership of transmission assets remains with the former vertically integrated utility and transmission operations are carried out by the RTO/ISO

Source: Created by REI based on utilities' corporate information

Observations above lead to the conclusion that even if ESR certainly offers a more favorable framework for RE deployment, additional factors must be considered for accelerated expansion.

State RE supportive policies are the next important factors to explain why penetration rates of RE differ from a State to another.

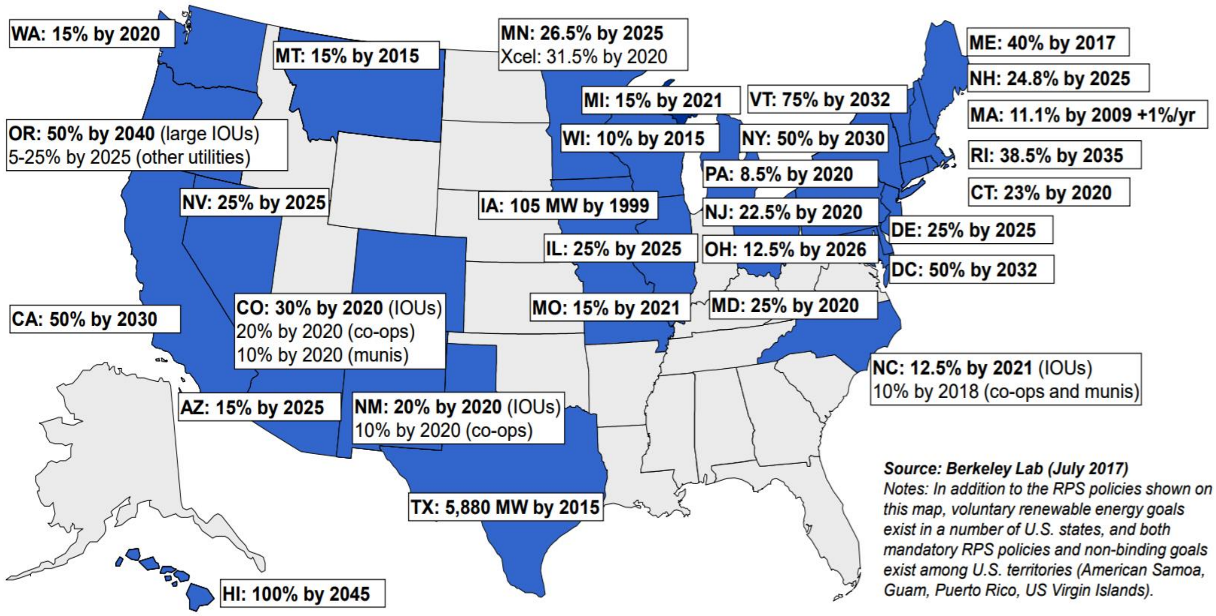
In the US both Federal and State policies coexist and they have been successful to encourage the developments of RE technologies. For instance, federal policies such as the production tax credit for wind and the investment tax credit for solar have importantly contributed to the expansion of these two technologies in the country. And at the State level, ambitious renewable portfolio standards (RPSs) have been key to unlock further progresses.

RPSs require or encourage electric utilities to provide their customers with a stated minimum share of electricity from eligible renewable resources (wind, solar, geothermal, biomass, some types of hydroelectricity…).[7]

RPSs did not only directly contributed to substantially increase RE, they also created markets for renewable energy certificates (RECs).[8] (The critical importance of RECs is discussed in "II 5 RE electricity tracking system in the US").

As of July 2017, 29 States and the District of Columbia had RPSs covering 56% of total US retail electricity sales (Map 6 on next page).

Map 6: RPS by State in the US



Note: Appendix C "State RPS Eligible RE Technologies" on pages 59-60 indicates for each State RPS eligible RE resources
Source: LBNL, U.S. Renewables Portfolio Standards 2017 Annual Status Report

The additional information provided by Map 6 are quite interesting. Beyond the fact that it shows more or less ambitious goals; e.g. Hawaii 100% by 2045, California and New York 50% by 2030 against Pennsylvania only 8.5% by 2020, it demonstrates that in some States without RPS such as North Dakota, South Dakota, Nebraska, Kansas, and Oklahoma it has been possible to significantly develop RE. This suggests that under certain conditions; abundant natural resources and moderate ESR a RPS may not be absolutely necessary. However, continuing earlier comparison between Colorado and Florida, two States where potential of natural resources are good and ESR did not take place, a RPS seems to be a very important driver for RE expansion. Indeed, Colorado has a relatively ambitious RPS whereas Florida has none, and it has been noted previously that RE expansion is proceeding in Colorado and not in Florida.

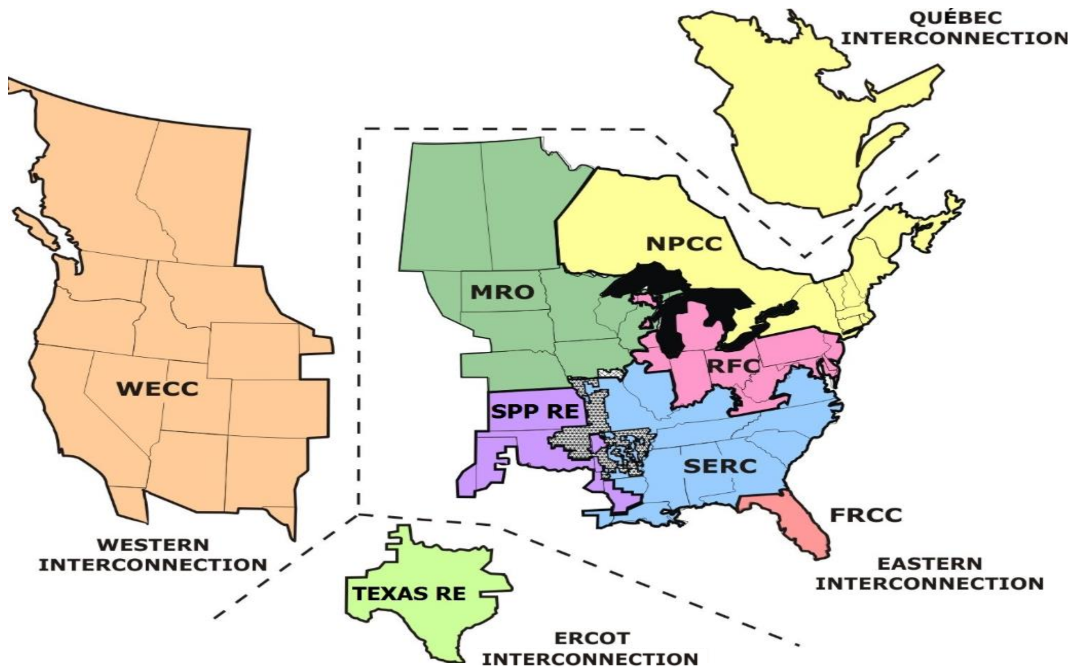
Feed-in tariff (FiT) policies also exist at State or utility levels in the US. In comparison with RPS, FiT is not a common policy tool in the US (in less than ten States) and usually only applies to relatively small-scale projects (maximum of a few megawatts (MW)). Though FiT played a key role in Japan and Europe to expand RE, this has not been the case in the US where RPS has been the major policy option to promote RE at the State level.[9]

These observations lead to the conclusion that under certain conditions such as abundant natural resources and progresses in ESR, a State RPS may not be of absolute necessity. However, even in the case of favorable natural resources if ESR has not started at all then a State RPS is critical for RE growth.

Finally, the last factor that may influence RE expansion are interconnections of electrical grids. Large balancing areas being advanced as tools for integrating into grids the variability from wind and solar power electricity generation.

The US power system (excluding Alaska and Hawaii) is divided into 3 synchronized grids; the Eastern Interconnection, the Western Interconnection, and the Electric Reliability Council of Texas (ERCOT) (Map 7). There are limited connections between the Eastern and Western Interconnections, and even fewer connections from ERCOT to the other grids.[10]

Map 7: US Power System Electrical Grids



Source: NERC, NERC Interconnections (accessed 5 April 2018)

The US power system is interconnected with Canada in the North and Mexico in the South. International interconnections between the US and its two neighbors date back to the very beginning of the 20th century; Canada 1901 and Mexico 1905.[11] As of the first half of 2017, there were close to 40 major transmission lines (i.e. greater than 69 kilovolts) between the US and Canada and more than 10 transmission lines – most of which for emergency purposes, not regular trade – between the US and Mexico.[12] In 2016, net imports of electricity accounted for about 1% of US electricity consumption.[13]

The US is traditionally a large net importer of electricity from Canada; more than 60TWh in 2016.[14] Electricity imported largely comes from hydropower generated in the Southeastern provinces of Canada (Ontario and Quebec) – exported to US Northeastern States (particularly New York and the region of New England; Maine, Vermont, New Hampshire, Massachusetts, Connecticut, and Rhode Island) and Michigan, in the Southcentral province of Manitoba – exported to US Midwestern States (Minnesota and North Dakota), and in the southwestern province of British Columbia – exported to US Pacific Northwestern States (Washington and Oregon).[15]

In comparison cross-border trade between the US and Mexico is much smaller; a little more than 10TWh in total (imports + exports) in 2016 and is not clearly unidirectional (for instance the US was a net importer of electricity from Mexico between 2010 and 2015 and a net exporter in 2016).[16] California, New Mexico, and Texas are the three US States interconnected with Mexico.[17]

Neither Alaska nor Hawaii are interconnected with any of the major US interconnections, or to any transmission or distribution network in Canada.[18]

Based on this information we can recognize Texas, Alaska, and Hawaii as electrical islands. Interestingly, two out of these three states are among RE leaders; Texas for wind and Hawaii for solar.

This leads to the conclusion that while the importance of interconnected electrical grids is not to be undermined (efforts regarding developments of interconnections for further RE deployment in the US is discussed in “II 3 Grid integration of VRE”) **limited interconnections are not decisively preventing RE breakthrough, i.e. it may make it more challenging, not impossible.**

Thus, it may be advanced that abundant natural resources, advancement of ESR, supportive policies, and well-developed electrical grids interconnections are forces which when combined enable massive expansion of wind and solar power. Nevertheless, even when all stars are not aligned significant progresses can be achieved based on economic, political, social and environmental grounds.

To illustrate the discussions of this section Table 3 provides examples of key enabling factors for wind and solar power deployment and achievements in different States.

Table 3: Assessment of Enabling Factors for Wind and Solar Deployment and Results in Selected States

State	Wind and solar potential	ESR	Supportive policies	Electrical grids interconnections	Wind + Solar share in electricity generation
California					22%
Colorado					20%
Florida					0%
Hawaii					17%
Oklahoma					32%
Pennsylvania					2%
Texas					15%

Conditions for wind and solar development:

Good Moderate Bad

Source: Created by REI based on information made available throughout this section

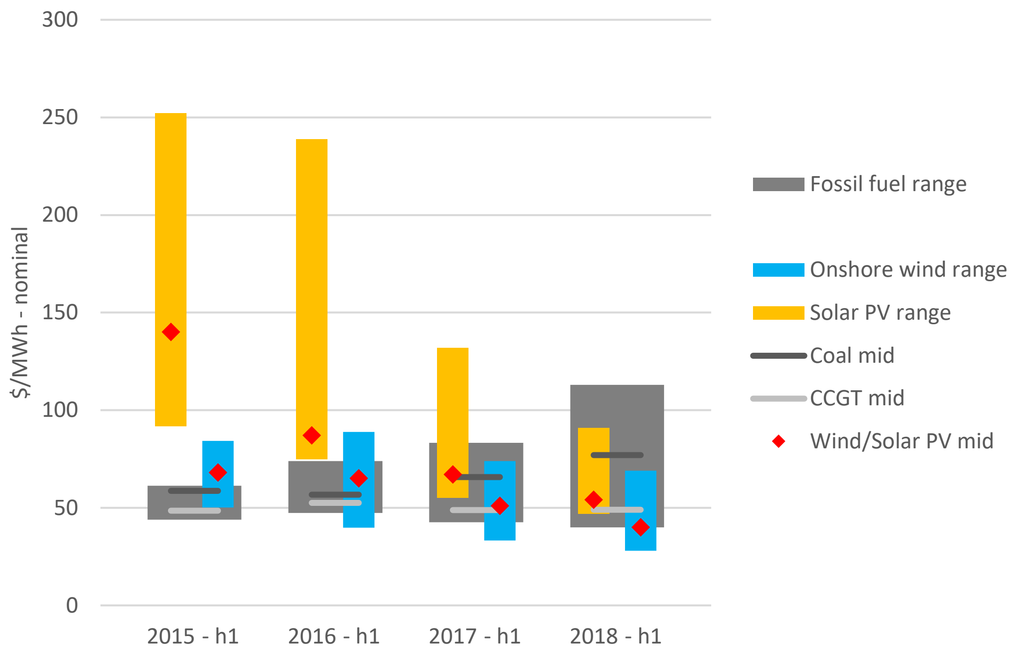
II BENEFITS AND CHALLENGES FROM RE EXPANSION

1 RE economic cost competitiveness

Significant deployment of onshore wind and solar PV is providing American consumers with cost competitive electricity prices thanks to dramatic cost reduction in both technologies.

On a levelized cost of electricity (LCOE) basis, since 2017 both onshore wind and solar PV are fully cost competitive with fossil power (i.e. coal and combined cycle gas turbine (CCGT)) in the US (Chart 12).

Chart 12: LCOE – Onshore Wind and Solar PV Cost Competitive with Fossil Power in the US

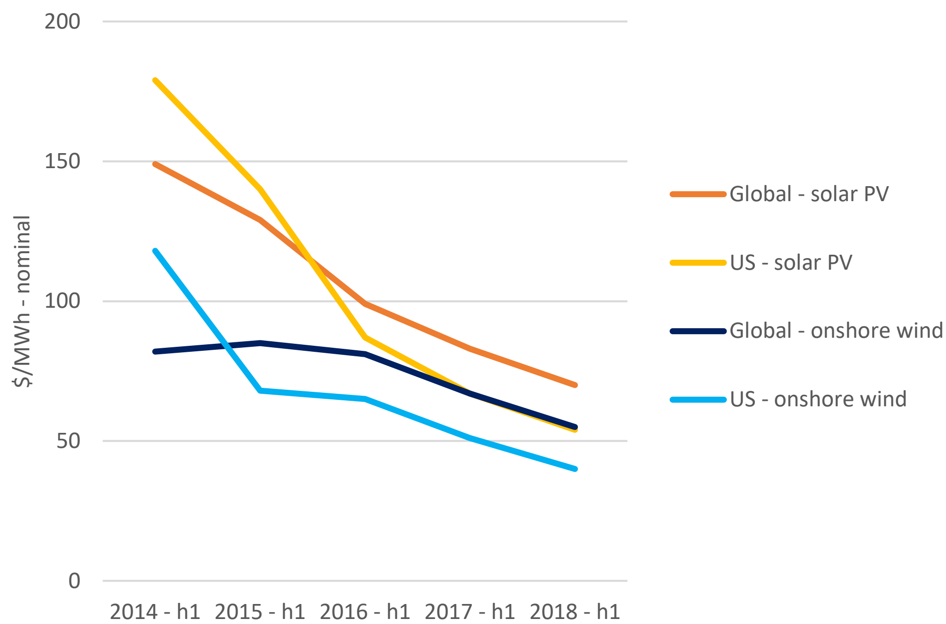


Notes: “Fossils range” includes coal and CCGT only. Operational durations; non-tracking solar PV 25 years, wind onshore 25 years, CCGT 35 years, and coal 30 years
Source: BNEF, Levelized Cost of Electricity

They are also much cheaper than nuclear power which LCOE is estimated between $94/megawatt-hour (MWh) and $196/MWh – mid-cost around $140/MWh.[19]

Though LCOE for onshore wind and solar PV used to be higher in the US than in the rest of the world in 2014, they are both lower now (Chart 13 on next page).

Chart 13: LCOE – Mid-Cost Onshore Wind and Solar PV, US VS. Global



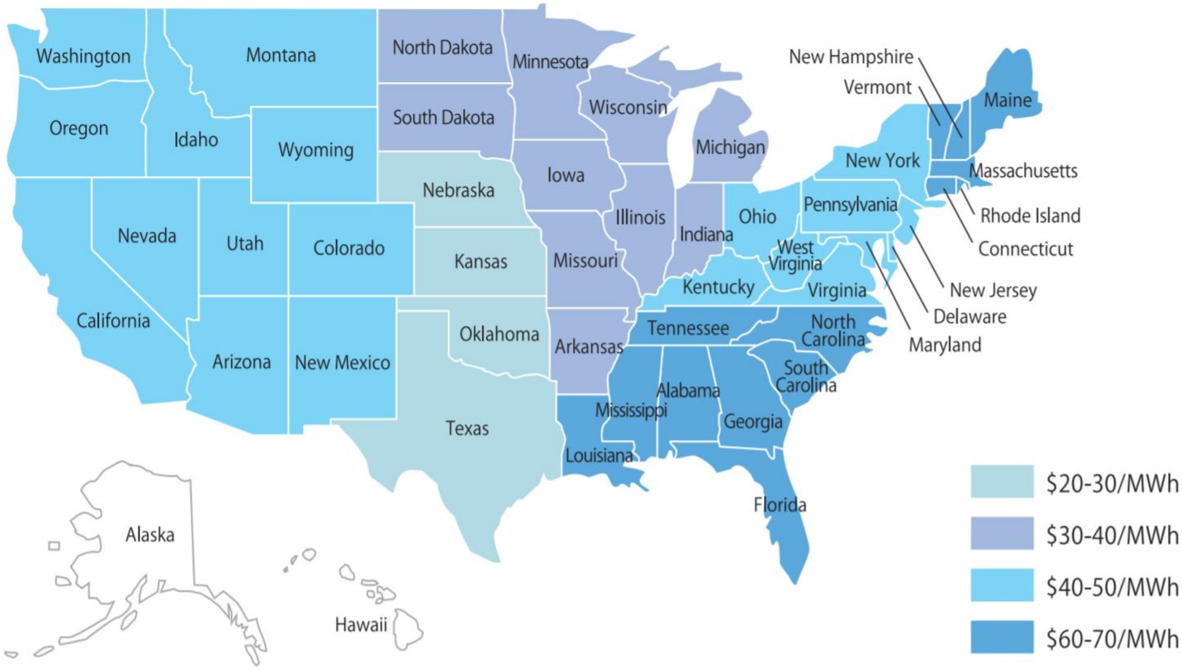
Note: Solar PV refers to non-tracking technology
Source: BNEF, Levelized Cost of Electricity

In comparison, mid-cost onshore wind and solar PV LCOE in Japan are about 2.5-3 times higher than in the US.

Because of different local conditions (natural resources, development costs…) cost competitiveness of onshore wind and solar PV varies across the country.

For instance, while onshore wind LCOE is estimated below $30/MWh in Texas, Oklahoma, Kansas, and Nebraska – which explains its success in traditional Republican States where economy prevails over environment, it is over $60/MWh in the Southeastern States of Louisiana, Mississippi, Alabama, Tennessee, Florida, Georgia, North Carolina and South Carolina (Map 8 on next page).

Map 8: Onshore Wind Unsubsidized LCOE by State 2018 – h1

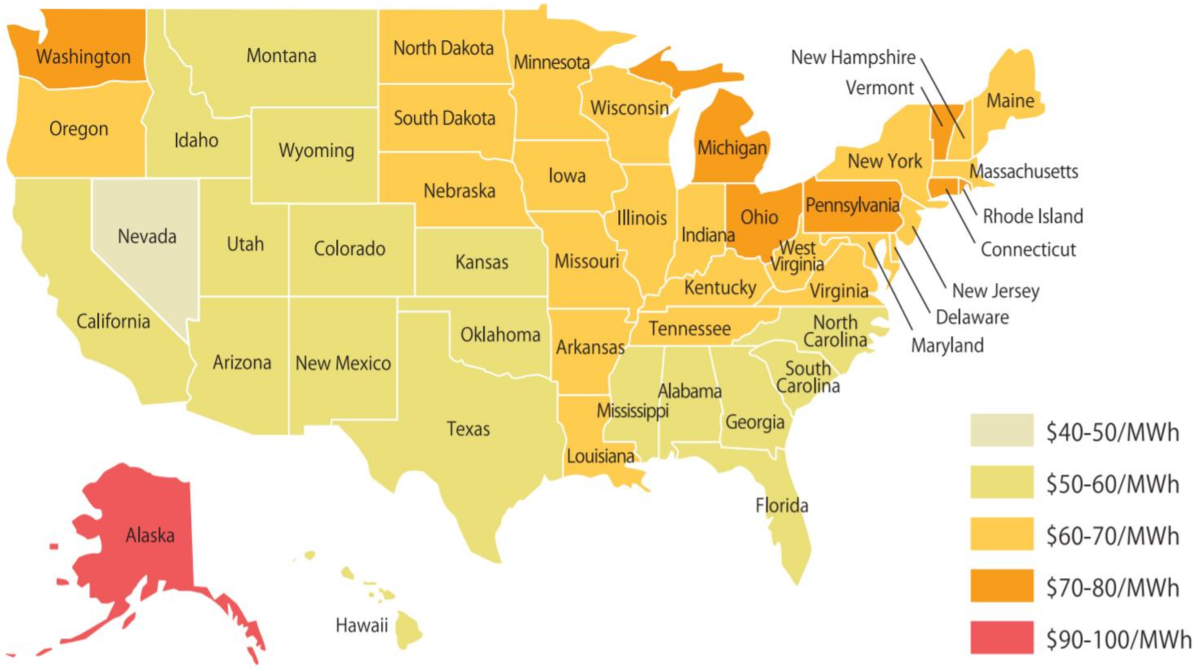


Disclaimer: BNEF collected data and analyzed the LCOE from a regional perspective and grouped states into regions

Source: Created by REI based on BNEF, Levelized Cost of Electricity March 2018

And solar PV LCOE is estimated below $60/MWh in many Southwestern States (California, Nevada, Utah, Arizona, Colorado, and New Mexico) and Southeastern States (Mississippi, Alabama, Georgia, Florida, North Carolina and South Carolina), as well as in Texas and Hawaii for example. That is lower than in the Northwestern State of Washington, a couple of States of the East North Central region of the Midwest (Michigan and Ohio), and in the Northeastern States of Pennsylvania, Connecticut, Rhode Island, and Vermont, where solar PV LCOE is at least $70/MWh, and much lower than in Alaska; over $90/MWh (Map 9 on next page).

Map 9: Solar PV (non-tracking) Unsubsidized LCOE by State 2018 – h1

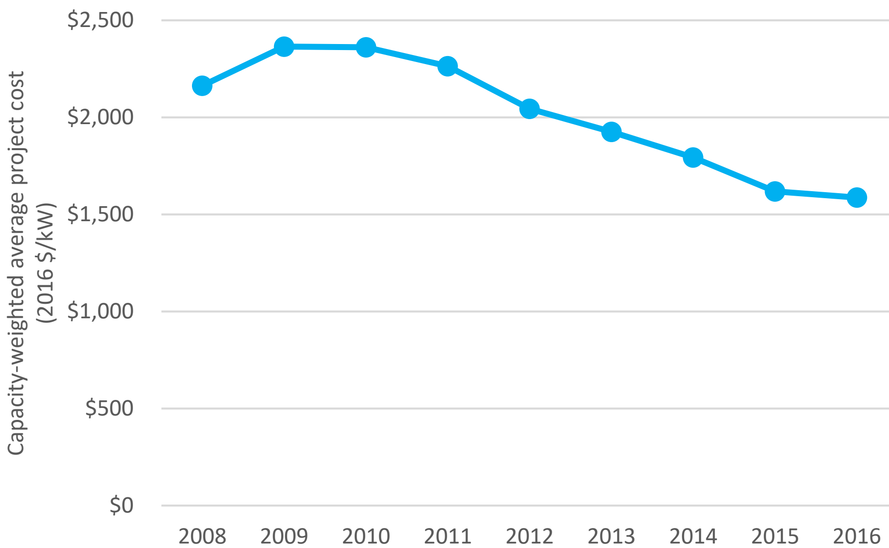


Note: The large majority of US solar PV cumulative capacity is based on non-tracking (or fixed tilt) systems. Since 2015 though, tracking systems dominate the utility-scale segment in the US. For comparison purposes with Japan, where essentially non-tracking systems have been deployed, LCOE for non-tracking systems only are presented throughout this section
Disclaimer: BNEF collected data and analyzed the LCOE from a regional perspective and grouped states into regions
Source: Created by REI based on BNEF, Levelized Cost of Electricity March 2018

Today's cost competitiveness of onshore wind and solar PV in the US results from dramatic cost reduction for both technologies over the past decade.

As for onshore wind, average turbine prices have substantially decreased from roughly $1,600/kilowatt (kW) at the end of 2008 to $800-$1,100/kW, or by 30-50%, despite increases in hub heights and especially rotor diameters.[20] And lower turbine prices have driven reductions in installed project costs (Chart 14 on next page).

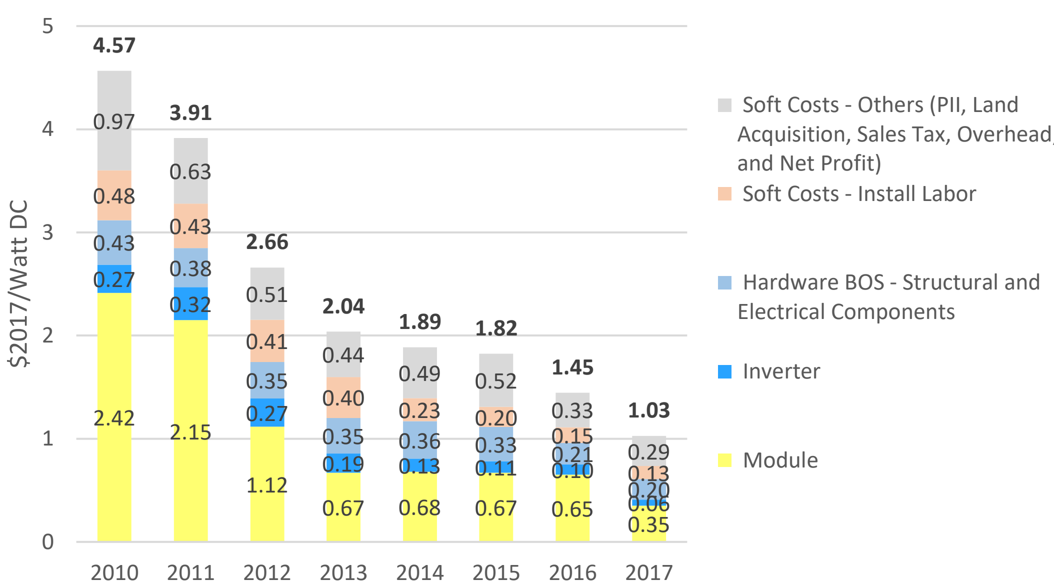
Chart 14: Installed Wind Power Project Costs in the US Over Time



Source: US DOE, [Wind Technologies Market Report 2016]

In the case of solar PV, mainly thanks to a collapse in module cost; -86% since the beginning of the decade, installed cost of solar PV dropped (Chart 15).

Chart 15: Utility-Scale Solar PV (non-tracking) System Cost in the US 2010-2017



Note: Fixed tilt 100 MW
Source: NREL, [U.S. Solar Photovoltaic System Cost Benchmark: Q1 2017]

And according to Bloomberg New Energy Finance (BNEF), as further deployment and technological progress unfold, it is expected that low cost onshore wind and solar PV will completely outcompete both coal and gas power by 2030.[21]

In this regard, the US Energy Information Administration (EIA) also forecasts that while RE expansion will take place in the coming decades the price of the electricity generation service will decrease over time in the US; from current $63/MWh to $60/MWh in 2030, and $56/MWh in 2050 (all in 2017 dollars).[22]

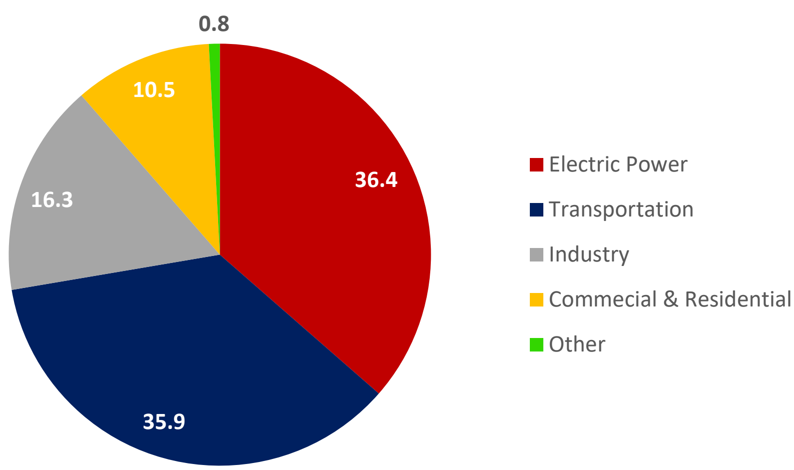
That is an excellent news for all electricity consumers in the US; from the large industrial groups facing international competition to the residential consumers seeking cheap power.

2 Reduction of CO_2 emissions

Massive expansion of RE, combined with energy efficiency improvements and development of cheap gas, is resulting in an impressive decarbonization of US electricity generation, drastically improving air quality and thus American residents' quality of life.

Carbon dioxide (CO_2) accounts for the very large majority of US greenhouse gas (GHG) emissions; 82% in 2016. In that year, CO_2 emissions from fossil fuel combustion accounted for 94% of total CO_2 emissions. And the first contributor to these emissions was the power sector, 36.4% of total CO_2 emissions from fossil fuel combustion (Chart 16). Making the US power sector a major GHG emitter of the US economy; 28% of the country's total GHG emissions.[23]

Chart 16: US CO_2 Emissions from Fossil Fuel Combustion 2016 (%)

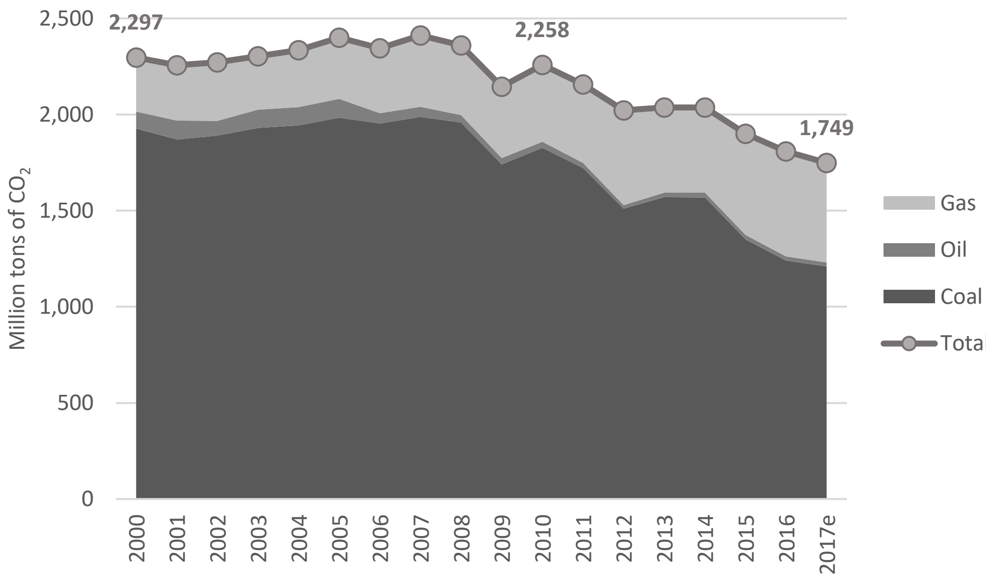


Source: US EPA, Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2016

Thanks to the significant deployment of RE, as well as improvements in energy efficiency, and increased reliance on relatively cleaner gas (approximately 400gCO_2/kWh for gas against 1,000gCO_2/kWh for coal)

CO_2 emissions from the US power sector have sharply declined since the beginning of the century; from 2,297 million tons of CO_2 in 2000 to 1,749 million tons of CO_2 in 2017, a 24% decrease (Chart 17).[24]

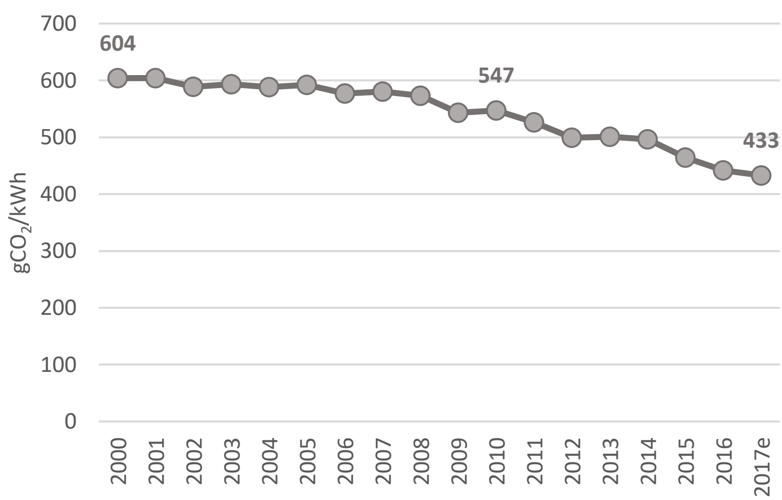
Chart 17: US CO_2 Emissions from Fossil Fuel Combustion for Electricity Generation 2000-2017



Sources: US EPA, [Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2015] and [Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2016], and US EIA, [Annual Electricity Report 2016] and [Monthly Electricity Report February 2018]

These improvements also translate into reduced emission intensity of the US electricity generation mix; from 604gCO_2/kWh in 2000 to 433gCO_2/kWh in 2017, or -28% (Chart 18).

Chart 18: US Emission Intensity of US Electricity Generation 2000-2017



Note: CO_2 emissions other than those from fossil fuel combustion are not included because they are negligible
Sources: US EPA, [Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2015] and [Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2016], and US EIA, [Annual Electricity Report 2010-2016] and [Monthly Electricity Report February 2018]

This compares with 512gCO_2/kWh in Japan in fiscal year 2016 and 314gCO_2/kWh in the European Union in 2017.[25]

It is important to highlight that most of the CO_2 emissions reduction took place between 2010 and 2017, precisely when RE deployment started to accelerate. And this is obviously not a coincidence. Fuel switching from coal to gas help to reduce CO_2 emissions because gas is relative less polluting than coal. And replacing coal with RE is much more effective because CO_2 emissions from RE electricity generation, and particularly from wind and solar, are negligible.

It has been observed (see Chart 2 on page 10) that between 2010 and 2017 electricity generation from RE increased by 284TWh. In the absence of RE growth, it is fair to assume that this amount of electricity would have been generated by a mix of fossil fuel resources. With emission intensity only from fossil power close to 700gCO_2/kWh in the US in 2017, it can be estimated that the massive expansion of RE enabled to avoid emissions of nearly 200 million tons of CO_2 in 2017. Without this accelerated deployment of RE, total CO_2 emissions from fossil fuel combustion in the US power sector would have reached almost 1,950 million tons in 2017, or 11% higher than they actually were. RE thus provided a major contribution in decarbonizing electricity generation in the US.

Additional efforts in deploying RE will help the US further reduce its carbon footprint, but progresses may not be as fast as could have been expected when previous President Obama announced the Clean Power Plan (CPP) in 2015. The CPP notably targets a nationwide 32% reduction of CO_2 emissions from the power sector by 2030 (compared with 2005).[26] It is currently proposed to be repealed under President Trump's administration.[27]

3 Grid integration of VRE

Though wind and solar power penetration has been fast and deep, especially in some parts of the country (discussed in "I 2 Regional penetration of RE; unevenly distributed progresses"), experience has proved their grid integration has so far not been an insurmountable challenge from a technical point view.

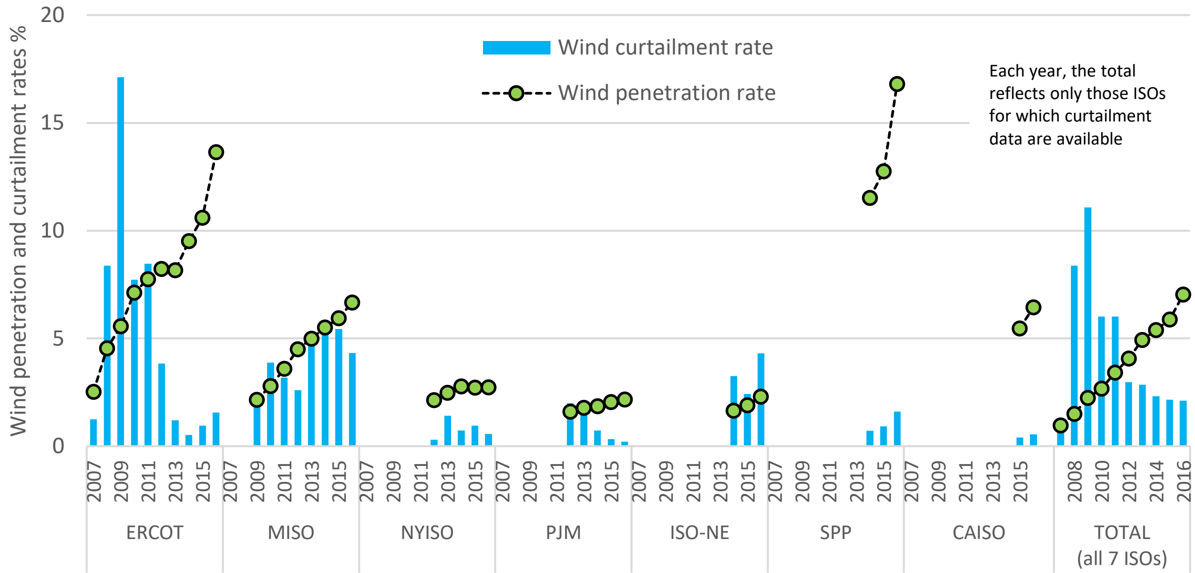
In recent years operators of many US electrical grids have demonstrated their ability in managing the integration of high shares of variable renewable energy (VRE): wind; 15-35%, and solar; 10-15%, of electricity generation on an annual basis. Without "wasting" much of total potential generation, i.e. with relatively low curtailment rates.

Curtailment is a reduction in the output of a generator from what could be produced given the resources available. It can occur, for example, because of a lack of transmission access or because of transmission congestion.[28]

In the US both wind and solar curtailment are low in States where they have been significantly deployed.

In the case of wind in 2016: in the Southwest Power Pool (SPP – covering mainly Oklahoma, Kansas, Nebraska, and parts of South Dakota and North Dakota, as well as some parts of Texas) where wind penetration reached almost 17%, curtailment rate was below 2% (Chart 19 on next page). And in ERCOT (essentially covering Texas) wind penetration was almost 14% and curtailment below 2% as well.

Chart 19: Wind Curtailment and Penetration Rates by US ISO 2007-2016

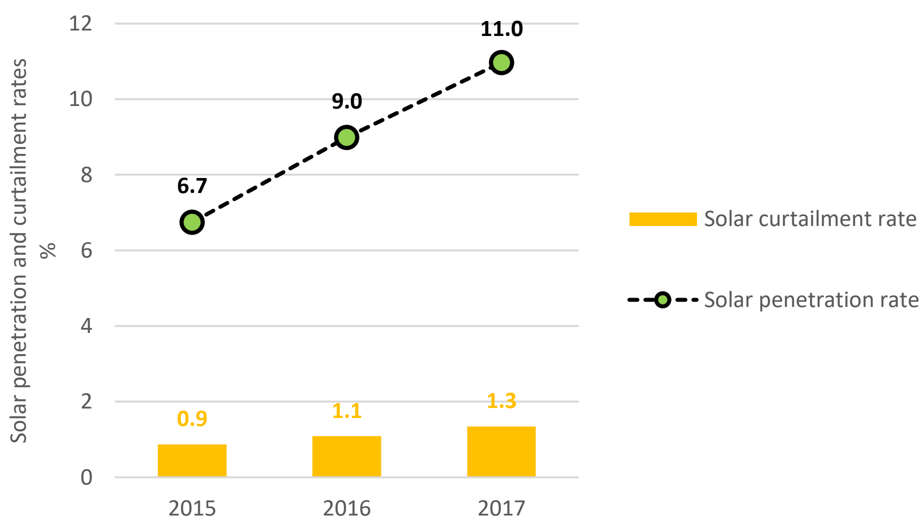


Notes: All curtailment percentages shown in the chart represent both forced and economic curtailment. PJM's 2012 curtailment estimate is for June through December only. Penetration rate based on electricity consumption, curtailment rate on potential electricity generation

Source: US DOE, Wind Technologies Market Report 2016

In the case of solar: California Independent System Operator (CAISO) (essentially covering California), the leading ISO when it comes to solar integration, already demonstrated that it is possible to successfully integrate much more than 10% of electricity consumption from solar on an annual basis and keep low curtailement rates (around 1%) (Chart 20).

Chart 20: Solar Curtailment and Penetration Rates in CAISO 2015-2017



Notes: Not including estimates for distributed solar that is not negligible (over 5GW). Penetration rate based on electricity consumption, curtailment rate on potential electricity generation

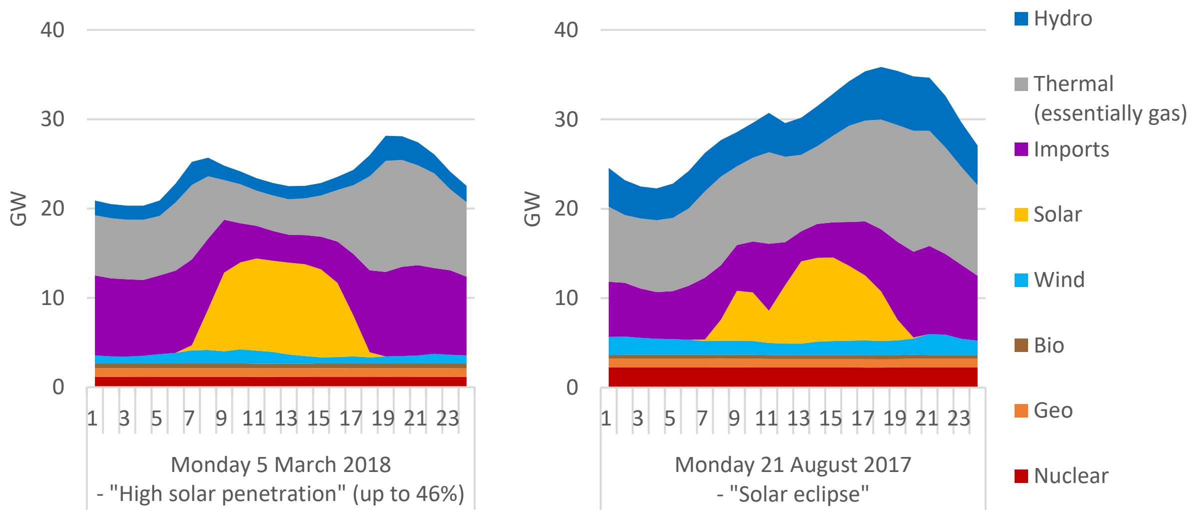
Source: CAISO, Managing Oversupply (accessed 26 March 2018)

These examples do not mean that integrating VRE is straightforward, but rather that solutions exist.

For instance, on Chart 19 (on previous page) it is possible to see that back in 2009 while penetration of wind power was modest – below 6% only, poorly interconnected ERCOT struggled in integrating wind power resulting in a very high curtailmemt rate of about 17%. Wind curtailement was successfully decreased thanks to the Competitive Renewable Energy Zones (CREZ), which primarily consisted in building and upgrading about 3,600 miles (or 5,800 kilometers) of transmission lines to deliver wind power from windy areas where it is generated to urban areas where it is consumed.[29] Most of which were completed by the end of 2013. And a move to more-efficient wholesale electric market designs.[30]

As for CAISO, current best solutions to integrate solar power are – by order of importance – uses of interconnections ("imports"), and flexible generation from gas and hydro power plants. Chart 21 concretely shows that either on a day with high penetration of solar or a more exceptional day with a solar eclipse, fluctuations in solar power are balanced by importing more or less power from outside CAISO and by ramping up or down output from conventional gas and hydro power plants.

Chart 21: Solar Power Integration in CAISO in Two Selected Days

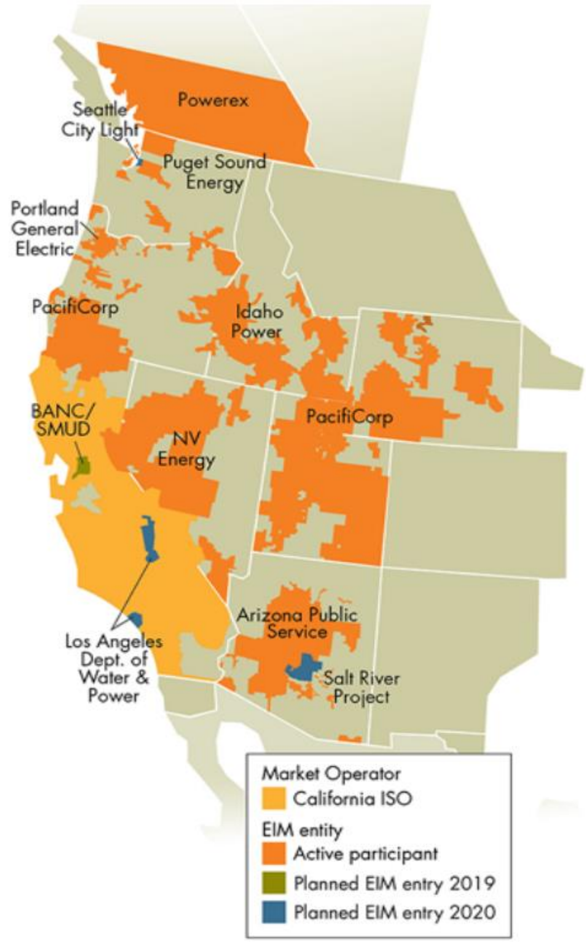


Source: CAISO, Renewables and Emissions Reports (accessed 9 April 2018)

Interconnections already play a significant role as a solution to integrate wind and solar power in the US. A role that could become even more important as pointed out by a number of dedicated studies on the integration of wind and solar by the National Renewable Energy Laboratory (NREL), which highlight that larger balancing areas provide greater flexibility and easier accomodation of VRE.[31]

In this regard, efforts of regional cooperation such as the expansion of regional energy partnerships under the umbrella of the Western Energy Imbalance Market (EIM) is a significant step forward (Map 10 on next page). The EIM is a real-time bulk power trading market, the first of its kind, in the Western US. Operated by CAISO, EIM's advanced market systems automatically find the lowest-cost energy to serve customer demand across a wide geographic area. Launched in 2014, and still expanding, the EIM improves the integration of wind and solar; by making best use of available generating resources within participating areas, and by signaling where potential grid investments could be profitable for the power system as grid bottlenecks arise.[32]

Map 10: Western EIM Active and Pending Participants



Source: Western EIM, [Western Energy Imbalance Market](#) (April 2018)

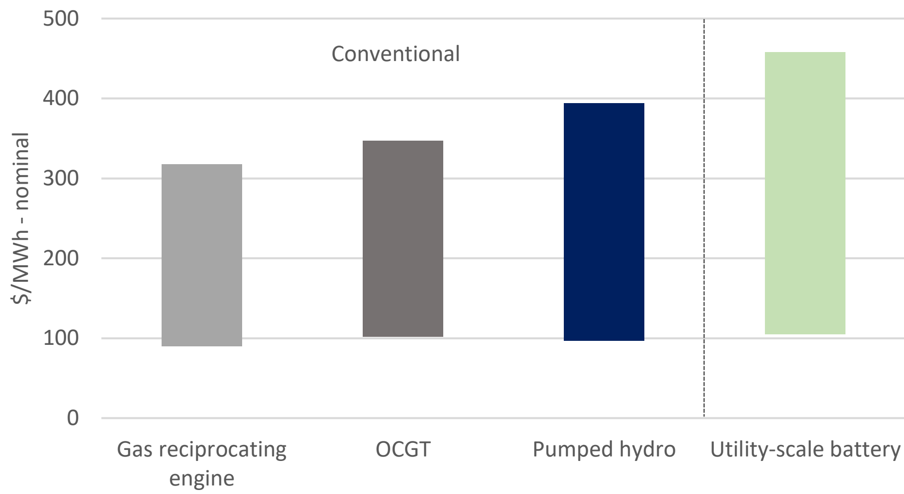
And additional international interconnection projects such as the Northern Pass or New England Clean Energy Connect, as well as the Champlain Hudson Power Express, between Northeastern US States (particularly Massachusetts and New York) and Canadian province of Quebec are expected to provide imports of clean cheap hydropower and further flexibility to the US power system.[33] The projects realized would increase by more than 2GW the interconnection capacity between the two systems, compared with approximately 18GW existing in 2016.[34]

Energy storage is another solution to help integrating VRE in the US.

Today's dominant energy storage technology in the US is pumped hydro; 22.8GW of capacity installed in 2017 (that is significant, but still much less than Japan; 27.6GW).[35]

Nevertheless, new "advanced" options start to appear and may change the landscape of energy storage in the US within the next decade. That is the case of batteries, which costs keep dramatically falling and begin to become a serious option to compete with conventional technologies such as gas reciprocating engine, pumped hydro, or open cycle gas turbine (OCGT), in providing flexibility services (Chart 22 on next page).[36]

Chart 22: LCOE – Batteries Becoming Competitive with Conventional Flexible Technologies in the US



Note: Regarding fossil fuel-based technologies, up to now, OCGT have been the most common form of peaking capacity across the world. Recently, however, this technology has been challenged by new types of gas reciprocating engines that have shorter start-up times and higher efficiency

Source: BNEF, Levelized Cost of Electricity March 2018

And the best may be yet to come soon with deployment of cost competitive RE+battery storage, which would make wind and solar unbeatable as dispatchable generation even for gas. A very promising sign of such development is the fact that US utility Xcel Energy received record low median wind+battery storage and solar PV+battery storage subsidized bids at \$21/MWh and \$36/MWh, respectively, at the end of 2017 (few additional information has been disclosed).[37]

At the forefront of this "advanced" energy storage expansion in the US, efforts are particularly remarkable in California where a couple of landmark legislations have been passed; Assembly Bill (AB) 2514 and AB 2868, and a supportive program launched; the Self-Generation Incentive Program (SGIP) in the past ten years.

In 2013, pursuant to AB 2514 the three largest investor-owned utilities in California – Pacific Gas and Electric (PG&E), San Diego Gas and Electric (SDG&E), and Southern California Edison (SCE) were mandated by the California Public Utilities Commission (CPUC) to procure 1,325MW of energy storage by 2020 (with installations required no later than the end of 2024), with specific targets for transmission, distribution, and customer-side energy storage systems.[38] As of February 2017, utilities had procured more than 475MW of energy storage.[39]

Passed in 2016, AB 2868 additionally requires the thee utilities to develop programs and investments for up to 500MW of distributed energy storage resources (i.e. connected to the distribution system or located on the customer side of the meter).[40]

And in 2008, the CPUC approved energy storage systems coupled with eligible SGIP technologies to receive incentives.[41] As of the end of 2016, over 700 behind-the-meter battery storage projects installed across the residential and non-residential sectors (i.e. commercial and industrial), representing almost 50MW of SGIP rebated capacity, received an upfront incentive from the Program.[42]

In Hawaii, where islands are not interconnected and plans to connect Oahu and Maui with an undersea cable have been abandoned, due to concerns about the project cost ($626 million-$1 billion) and environmental impacts from the cable, energy storage solutions are increasingly targeted to help reaching the State goal of 100% RE electricity by 2045.[43] Hawaiian Electric Company (HECO), the main electric utility in Hawaii, now has more than 10 energy storage projects underway or planned (the largest being a battery energy storage project with a power output of 90MW planned for the third quarter of 2018).[44] In addition, the Customer Self-Supply (CSS) program encourages the deployment of distributed energy storage like batteries as it enables customers to only install private rooftop solar systems that do not export power to the utility grid.[45] CSS systems are eligible for expedited review and approval even in areas with existing voltage limitations (areas of high solar PV penetration).

Finally, another existing solution to deal with the variability of wind and solar power in the US may be demand response (DR).

DR covers a wide range of actions (e.g. contracted load curtailment, time-of-use tariff…) by electric utilities and their customers to reduce power demand at specific times.

Aggregated demand resource participation in US RTO and ISO DR programs reached a total of almost 29GW in 2016 – 5.7% of their peak demand, with progresses unvelenly distributed (Table 4).

Table 4: Demand Resource Participation in US RTO and ISO DR Programs in 2016

RTO/ISO	Demand resources (GW)	Percent of peak demand
California ISO (CAISO)	2.0	4.3
Electric Reliability Council of Texas (ERCOT)	2.3	2.9
ISO New England (ISO-NE)	2.6	10.2
Midcontinent Independent System Operator (MISO)	10.7	8.9
New York Independent System Operator (NYISO)	1.3	3.9
PJM Interconnection (PJM)	9.8	6.5
Southwest Power Pool (SPP)	0	0
Total RTO/ISO	**28.7**	**5.7**

Source: FERC, Assessment of Demand Response and Advanced Metering 2017

The (slight) majority of potential peak demand savings from retail DR programs comes from the industrial sector. More than a quarter from the residential sector. And the remaining essentially from the commercial sector.[46]

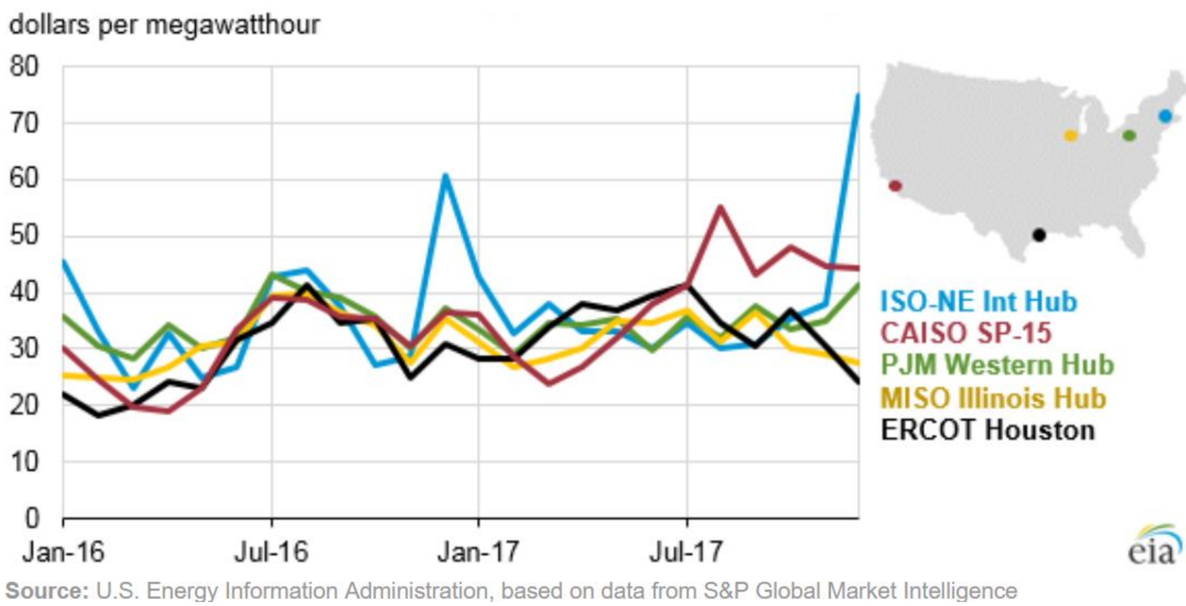
4 Market integration of close to zero marginal cost RE

In a context of stagnating electricity consumption and low gas prices, close to zero marginal costs wind and solar power push coal and nuclear power back in the merit order and out of competitive markets. Some major US power generating companies have painfully failed to address this challenge.

Because of their lower marginal costs, which are negligible ("close to zero"), wind and solar power are to be dispatched first to meet electricity demand (merit order). When electricity consumption does not increase, as it is the case in the US, additional electricity generation from new wind and solar power generation units reduces the amount of electricity to be generated from power plants with the highest marginal costs (e.g. gas, coal, nuclear). Furthermore, in competitive power markets prices are set by the marginal costs of the marginal units. In a context of stagnating demand increasing penetration of wind and solar power also results in lower market prices as the most expensive power stations are pushed out of the market due to their higher marginal costs. For fossil and nuclear power plants that is a terrible double blow; they sell less electricity and at lower prices.

In the US in the past two years wholesale electricity prices have been quite low (Chart 23). For instance, roughly between $20/MWh and $40/MWh in ERCOT, between $20/MWh and $55/MWh in CAISO, between $25/MWh and $40/MWh in MISO, and between $30/MWh and $45/MWh in PJM (all on a monthly average basis).

Chart 23: Monthly Average Wholesale Electricity Prices at Selected US Trading Hubs 2016-2017



Source: US EIA, Monthly Average Wholesale Electricity Prices at Selected Trading Hubs, 2016-2017

These developments, in combination with more stringent environmental requirements for coal power generation (in particular the Mercury and Air Toxics Standards limiting emissions from power plants), have rung the death knell for more than half of the US coal power plant fleet within 7 years only. Indeed, as of October 2017, 262 coal power plants had retired or announced to retire since 2010, and only 261 remained.[47] Another striking fact that coal power situation has become critical is that only half of US coal power plants earned enough revenue last year to cover their operating expenses.[48]

And US nuclear power plants are not doing much better. In 2017, more than half of US nuclear reactors (out of a total of 99 operational reactors with a total combined capacity of roughly 100 GW) were losing money with losses totaling about $2.9 billion a year.[49] In this context, unprofitable nuclear power reactors are closing across the country.[50] Since 2013 six nuclear reactors shut down (total combined capacity;

almost 5GW). And at least another twelve have announced early retirement plans (total combined capacity; more than 11GW). Following these closures there would remain 87 reactors in operation with a total combined capacity of 89GW.

Almost all these closures or announced closures come nearly a decade or more before scheduled license expirations of these reactors (after 40 years of operation, or 60 years when license for an additional 20 years of operation has been granted), i.e. even though they could technically operate for decades (Table 5).

Table 5: US Nuclear Power Reactor Closures for Economic Reasons Since 2013

Reactor name (State)	Closure year	Scheduled license expiration year	Net Capacity (MW)
Crystal River-3 (Florida)	2013	2016	860
Kewaunee (Wisconsin)	2013	2033	566
San Onofre-2&3 (California)	2013	2022	2,150
Vermont Yankee (Vermont)	2014	2032	605
Fort Calhoun-1 (Nebraska)	2016	2033	482
Reactor name (State)	Planned closure year	Scheduled license expiration year	Net Capacity (MW)
Oyster Creek (New Jersey)	2018	2029	619
Pilgrim-1 (Massachusetts)	2019	2032	677
Three Mile Island-1 (Pennsylvania)	2019	2034	819
Davis-Besse-1 (Ohio)	2020	2037	894
Beaver Valley-1&2 (Pennsylvania)	2021	2036 & 2047	1,826
Perry-1 (Ohio)	2021	2026	1,256
Indian Point-2&3 (New York)	2021	Under review	2,060
Palisades (Michigan)	2022	2031	805
Diablo Canyon-1&2 (California)	2025	2024 & 2025	2,256

Sources: IAEA, Country Statistics: United States of America, US NRC, Status of Initial License Renewal Applications and Industry Initiatives, Power Generating Companies, Oyster Creek, Pilgrim, Three Mile Island, Davis-Besse, Beaver Valley, Perry, Indian Point, Palisades, and Diablo Canyon (all accessed 11 April 2018)

And new builds are unlikely to save nuclear power as the latest three nuclear power projects have been major fails. In 2017, for its first full-year of operation Watts Bar 2 (Tennessee), which commercial operation started more than 43 years after beginning of construction(!) – reached a very modest 49% capacity factor.[51] In July 2017, the construction of two reactors at VC Summer (South Carolina) nuclear power plant was abandonned after investments of $9 billion, because costs could reach $25 billion – more than twice the initial $11.5 billion estimate – following numerous constuction problems and years of delay.[52] And expansion of Vogtle (Georgia) nuclear power plant is also a nightmare, plagued by delays and cost overruns total bill for new reactors 3 and 4 (1.1GW each) is now expected to be $25-$27 billion against $14 billion originally expected.[53] The outlook for the "*nuclear renaissance*" has thus never been so bleak.

As a result of these trends, businesses of power generating companies heavily relying on fossil, especially coal, and nuclear power plants are under stress. This is best illustrated by the bankruptcies in recent years of two major US power generating companies; Energy Future Holdings (EFH) and FirstEnergy (FE).

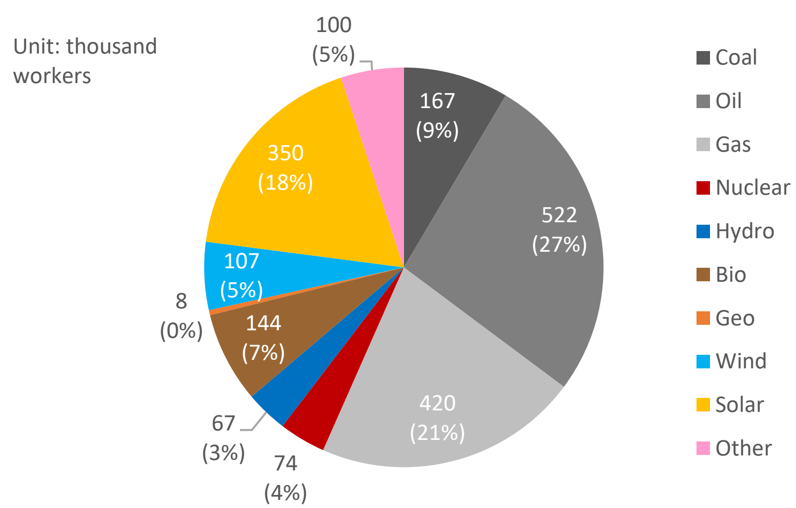
In 2014, EFH, the biggest power company in Texas, filed for bankruptcy as the coal-fired and nuclear power plants of its generating unit Luminant (more than 15GW of power capacity in Texas out of which roughly two-thirds were coal and nuclear) were outcompeted by cheaper gas and wind power.[54]

In 2018, FE filed for bankruptcy for its competitive power generation subsidiaries, which operate power plants (including three nuclear power plants that are now heading for closures; Davis-Besse, Beaver Valley, and Perry) in the Midwest and mid-Atlantic, for the same reason.[55]

Coal and nuclear power plants may now rely on subsidies for their survival. This has been the case for four of Exelon's fifteen nuclear power plants (Exelon is the US largest nuclear fleet owner); Clinton (Illinois), Quad Cities (Illinois), Fitzpatrick (New York), and Ginna (New York), which were rescued in 2016 by State legislations.[56]

However, one may question the rationality of subsidizing two old polluting technologies, employing in the case of coal more than twice less workers than solar; approximately 167,000 against 350,000, and in the case of nuclear 30% less than wind; 74,000 against 107,000 (Chart 24).

Chart 24: US Electric Power Generation and Fuels Employment by Technology Q2 2017



Note: Employment in electric power generation and fuels combined
Source: EFI & NASEO, [U.S. Energy and Employment Report 2018]

Though coal and nuclear power have been particularly suffering from current market conditions, they have not been the only ones. For instance, in 2017, NRG Energy subsidiary GenOn that used to largely rely on gas went bankrupt as well.[57] This may serve as a warning to Japanese power companies like JERA and J-Power, which are both currently constructing new gas power plants in the US.[58]

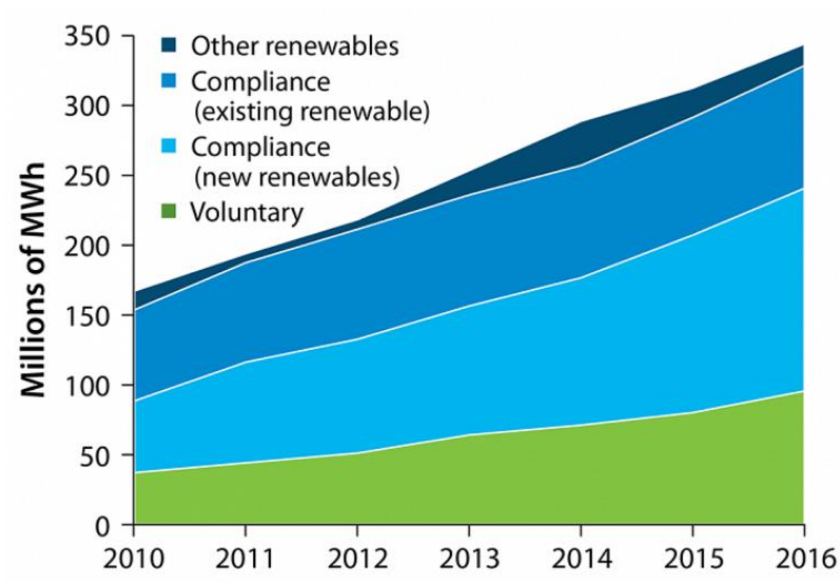
To avoid this gloomy destiny forward-thinking power generating have opted for a different strategy based on a massive deployment of wind and solar power (discussed in "III 1 Electric utilities").

5 Keeping track of RE electricity

In a context of growing demand for RE electricity in the US, either for obligatory of voluntary purposes, it is of critical importance to ensure that consumers are properly meeting their goals. Therefore, accounting, tracking, and assigning ownership to renewable electricity generation and use is another challenge. It requires a strict application of efficient rules and establishment of an effective system. Renewable energy certificates (RECs) play this important role in the US.

Sales in renewable electricity markets (excluding large hydropower) are significant; about 340TWh in 2016, out of which roughly 230TWh for compliance and 95TWh for voluntary purchases. And they are growing fast; 2016 sales are roughly at least double those of 2010 in all cases (2010: total sales; over 160TWh, compliance; about 115TWh, and voluntary; 37TWh). RECs keep track of these sales (Chart 25).[59]

Chart 25: RE Sales in Voluntary, Compliance, and Other Markets 2010-2016



Notes: Excludes large hydropower. "Other renewables" includes utility RE purchasing beyond RPS requirements and on-site generation

Source: NREL, Voluntary Green Power Procurement (accessed 26 April 2018)

RECs are certificates awarded to certify the generation of one unit of RE (1 MWh of electricity in the US). It represents the property rights to the environmental, social, and other non-power attributes of RE electricity generation.[60] In systems based on RECs, certificates can be accumulated to meet RE obligations and also provide a tool for trading among generators and/or consumers. Moreover, they are a means of enabling purchases of voluntary green electricity.[61]

From a practical point of view, RECs include several data attributes such as certificate data, certificate type, tracking system ID, renewable fuel type, renewable facility location… (Table 6 on next page).

Table 6: RECs Data Attributes in the US

Certificate data
Certificate type
Tracking system ID
Renewable fuel type
Renewable facility location
Nameplate capacity of project
Project name
Project vintage (build date)
Certificate (generation) vintage
Certificate unique identification number
Utility to which project is interconnected
Eligibility for certification or RPS
Emissions rate of the renewable resource

Note: This list is not exhaustive and, depending on the market in which the REC is generated, other attributes may be associated with the certificate

Source: US EPA, Renewable Energy Certificates

From a legal perspective, in the US, RECs are the instrument recognized by law that electricity consumers must use to substantiate renewable electricity claims. They are supported by several different levels of government, regional electricity transmission authorities, non-governmental organizations, and trade associations, as well as in US case law.[62]

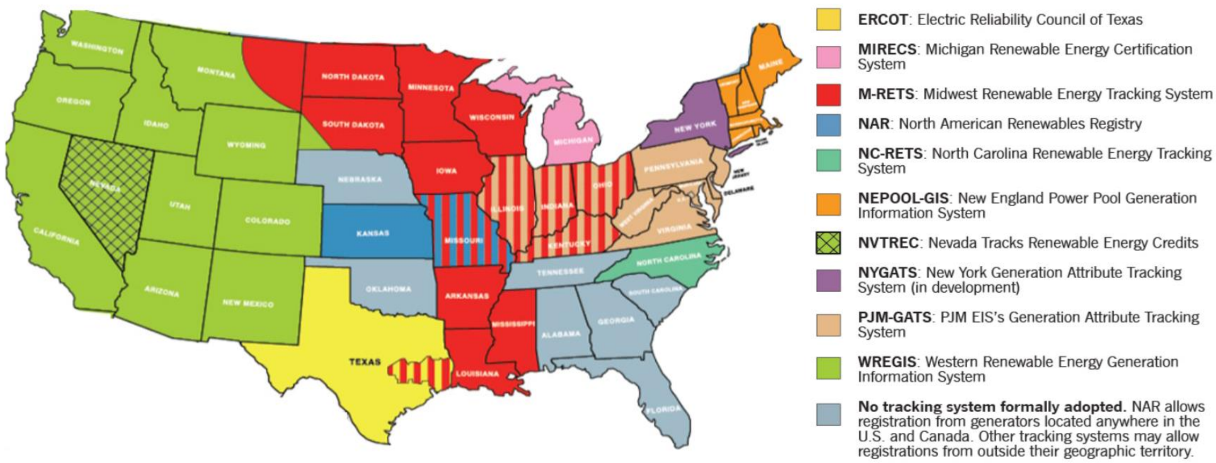
From a technical point of view, there are two approaches to verify RECs ownership in US energy markets; certificate-based tracking systems, and contract-path tracking method.[63]

Certificate-based tracking systems are typically electronic databases that register basic information about each MWh of renewable generation in a specific US geographical region. These systems issue RECs to the generator, signifying that a MWh of renewable electricity has been delivered to the grid. They are emerging as the preferable method for tracking wholesale RE because they can be highly automated, contain specific information about each MWh, and are accessible over the internet to market participants.[64]

The contract-path tracking method is widely used and is the oldest method utilized in the market to verify, track, and trace the chain of custody of RE ownership from a generator to the end-customer. It is characterized by a third-party audit supported by declarations, sworn statements, contract receipts, and other proof of generation and transfer of ownership to the ultimate end-user. Metered generation data are often used to support and verify such attestations and supply contracts. Concretely, third-party independent auditors verify that the green power behind the product was produced and placed on the utility grid and help verify the product environmental benefit.[65]

Map 11 below shows REC tracking systems by location in the US as of May 2015.

Map 11: REC Tracking Systems in the US



Note: There is no tracking system formally adopted in Alaska and Hawaii
Source: ETNNA, Renewable Energy Certificate Tracking Systems in North America (accessed 16 April 2018)

Finally, from an economic perspective, RECs through renewable electricity mandatory markets and voluntary sourcing offer the opportunity for participants (i.e. either those that are required to buy renewable electricity or those who want to buy it voluntarily), to procure RE-based electricity at the lowest cost by providing price signals. This enables participants to lead an arbitrage with different options such as installing their own RE projects or purchase renewable electricity directly from a RE project through a power purchase agreement (PPA) for example, when possible.[66]

Mandatory markets result from political decisions such as States RPSs, which require some electric service providers to have a minimum amount of RE in their electricity supply and are a major demand driver for RECs. Voluntary sourcing, or green power sourcing, are driven by consumer preference for certain types of RE and allow consumers to go above and beyond what mandatory policies require and to reduce further the environmental impact of their electricity.

Theoretically, price formation in mandatory markets tends to be affected by regulatory targets and associated penalties creating market price distortion. In comparison, prices in voluntary sourcing better reflect the balance between supply and demand.[67]

Practically, prices for RECs used for compliance purposes tend to be higher due to RPSs requiring utilities to source RECs from specific States or regions, or technologies. This limits the supply of eligible RECs while ensuring their demand causing upward pressure on prices. Depending on States RPS ambition levels prices of RECs used for RPS compliance vary significantly. For instance, in August 2017, they were close to $0/MWh (excluding solar RECs) in Texas because RPS target for wind power has been largely exceeded leading to a situation of RECs oversupply. And around $20/MWh in the Northeastern States of Connecticut, New Hampshire, Massachusetts, and Rhode Island due to more challenging conditions to meet RPS targets. Not facing the restrictions aforementioned and being flooded by cheap wind power from States like Texas or Oklahoma, RECs prices for voluntary sourcing have remained very low for years; below $2/MWh on a national basis since at least 2010.[68]

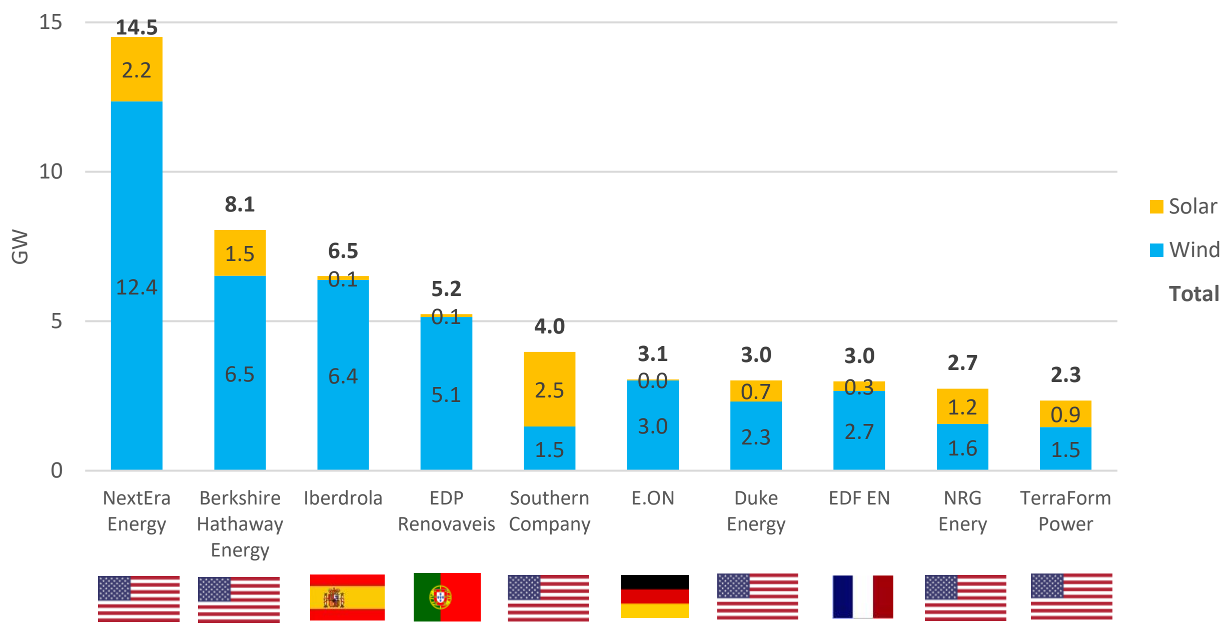
III THE LEADERS OF RE DEPLOYMENT

1 Electric utilities

In the competitive segments of the US power sector forward-thinking generators and suppliers are leading the change by adding gigawatts of wind and solar power capacity and by introducing new business models focusing on offering RE electricity through various electricity rate-based mechanisms, community solar utility programs, and customers' electricity consumption optimization tools and services…

Among leaders in wind and solar power generating companies in the US, the undisputed #1 is American group NextEra Energy (Chart 26). NextEra Energy is one of the US biggest electric power generating companies, almost 45GW total power capacity (including fossil, nuclear, and RE), and owns by far the largest wind and solar portfolio; 12.4GW and 2.2GW, respectively – roughly 10% of the country's total combined wind and solar power capacity, and a third of the group's total power capacity in the country (all figures at the end of 2017).[69]

Chart 26: Largest Wind and Solar Power Generating Companies in the US 2017



Note: Based on ownership share

Source Sources: Power Generating Companies Annual Reports 2017

Second, with almost twice less wind and solar power capacity, comes another large American power generating Berkshire Hathaway Energy (BHE) (total group capacity; 30GW) with "only" 6.5GW of wind and 1.5GW of solar – over a quarter of the group's total power capacity [70]

Among the other American power generating companies, follow Southern Company and Duke Energy, two of the largest power generating companies in the US, with total power capacity of 47GW and 52GW, respectively.[71] Though wind and solar still account for a relatively modest share of their total capacity; 8% for Southern Company and 6% for Duke Energy, both companies have made progresses in recent years.

Especially Southern Company, which through acquisitions notably, has tripled its solar power portfolio within the last two years making it one of the largest in the country.[72]

Other key actors in the expansion of wind and solar power capacity in the US are European power generating companies. At the end of 2017, Spanish Iberdrola owned over 6GW of wind and solar power capacity, Portuguese EDP Renovaveis more than 5GW, and German E.ON and French EDF EN about 3GW.[73] Not in Chart 26, Italian giant Enel also had about 2GW of wind and solar power capacity as well.[74]

When investing in new wind and solar power in the US, European power generating companies have an important economic advantage over their American peers; they have almost no fossil and nuclear power assets in the US to be outcompeted by cost competitive close to zero marginal cost RE.

This advantage obviously does not only belong to European power companies. Japanese power companies could also be more aggressive than they have been until now. Only Tokyo Electric Power Company (TEPCO), through its share in Eurus Energy, has been making some inroads in the US wind and solar power markets until now (ownership of 0.2GW of wind and solar).[75]

This opportunity is not to be underestimated at a time when power generating companies in the US are still trying to find the right solution regarding how to balance their fossil and nuclear portfolios with growing capacity of wind and solar. In this regard, though market fundamentals seem to designate wind and solar as the winners of the US power sector transformation, it has not prevented American large power generating company NRG Energy (total group capacity in the US in 2017; 29GW) to recently refocus its power generating business on fossil power. Indeed, the group announced the sale of its subsidiaries NRG Yield and NRG renewables platform, involved in wind and solar projects, in February 2018 – despite the bankruptcy of its essentially fossil power-based subsidiary GenOn in 2017.[76]

At the other end of the power sector value chain, power supplying companies in the US are also introducing innovative business models with various offers around RE and solutions for their integration. These mainly focus on delivery of RE electricity through various electricity rate-based mechanisms, community solar utility programs, and customers' electricity consumption optimization tools and services.

Regarding delivery of RE electricity, US suppliers offer three types of green power procurement mechanisms; competitive suppliers green pricing, utility green pricing, and utility renewable contracts.[77]

The "competitive suppliers" mechanism refers to the possibility for customers in competitive electricity markets to select a green power option from an alternative retail electricity supplier. Competitive suppliers may charge a premium for the green power product. Some suppliers only offer products with high RE content, and others with only nominally more RE than required by States RPSs. This mechanism sales reached 16TWh in 2016 with participation of 2 million customers. Texas wind power is a particularly popular option in the competitive supplier market.[78]

The "utility green pricing" mechanism refers to the possibility for utility customers to procure green power on a monthly basis through an added fee on their utility bill. Many utilities sell green power to residential and non-residential customers through utility green pricing programs. Typically, utilities generate or procure green power and retire RECs on behalf of customers in proportion to the quantity of green power purchased by the customers. This mechanism sales reached 8TWh in 2016 with participation of 0.8 million customers. And the average premium was about 2 cents/kWh for both residential and non-residential customers. For example, utility green pricing programs include SCE (California) "Green Rates," which enables residential customers and businesses to procure solar power from developers within the utility service territory to meet either 50% or 100% of their electricity consumption against an added fee ranging from approximately to 2 cents/kWh and 5 cents/kWh applicable on each kWh consumed covered by the subscription, and with the possibility to de-enroll at any time without penalty.[79]

And the “utility renewable contracts” refers to the possibility for utility customers to procure green power from their utility through a special tariff (e.g. “utility green tariffs”) or bilateral contract, typically on a long-term basis sourced from a new RE generator. This last mechanism is more recent and rather targets large commercial customers.[80]

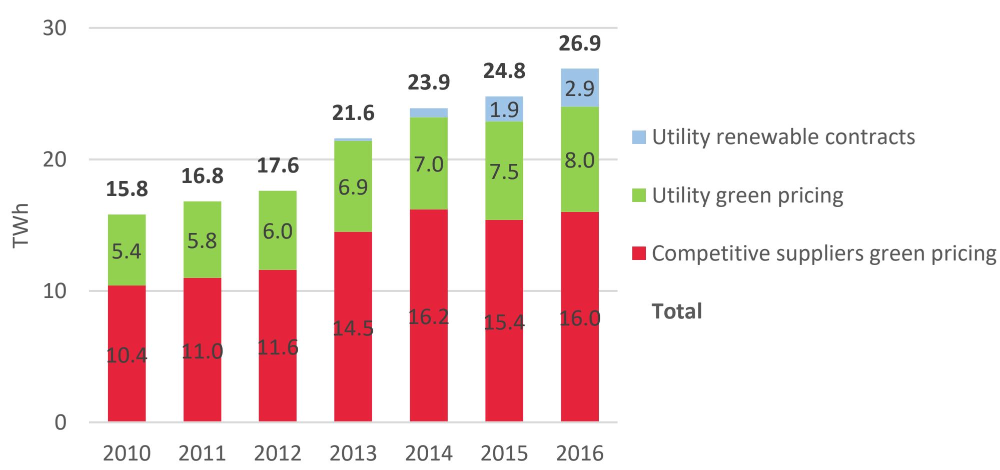
Compared with green pricing programs there are three differences. Renewable contracts may, depending on the program structure, specify the resource and project from which to procure RE. Customers pay for green power through a bilateral contract or green tariff rate rather than a premium added to the customer’s existing service and get some credit for the energy and capacity provided by their RE purchase. And renewable contracts are usually based on long-term agreements between consumers, utilities, and generators.[81]

As of June 2017, at least 12 RE projects have been contracted via a bilateral agreement. These includes projects between MidAmerican Energy (subsidiary of BHE) and Google for a 407MW wind farm, and between Dominion Virginia Power and Amazon Web Services for an 80MW solar farm.[82]

Utility green tariffs, which are available to a class of customers and allow multiple customers to procure RE under the same terms, have so far generally been limited to large non-residential due to eligibility criteria (e.g. large demand, high load factors…).[83] Over 10 utilities in 12 States offer such tariffs, among which; Duke Energy (North Carolina), Xcel Energy (Colorado and Minnesota), and NV Energy (Nevada). As of June 2017, close to 1GW of RE capacity had been procured through utility green tariffs. And with 449MW (all solar PV) the NV Energy “Green Energy Rider” program had resulted in the most contracted green power capacity.[84]

From below 1.8 million consumers in the US purchasing RE electricity from their suppliers in 2010, there were over 2.8 million in 2016.[85] And this rising demand for clean energy has resulted in a 70% increase in suppliers’ sales of RE electricity between 2010 and 2016 with growth in all types of offers (Chart 27).

Chart 27: US Suppliers Green Power Sales



Source: NREL, Status and Trends in the U.S. Voluntary Green Power Market (2016 Data)

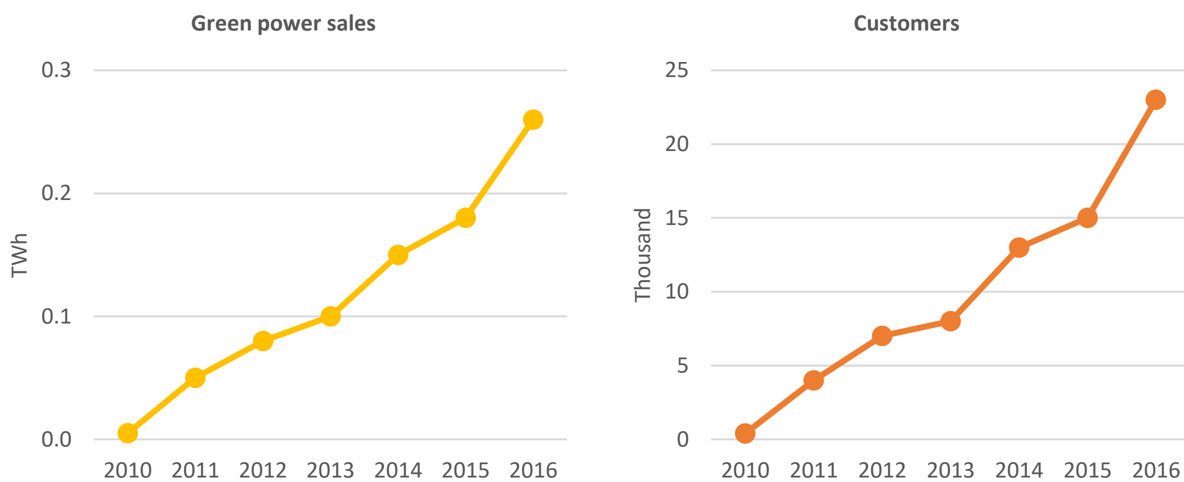
Beyond these various forms of delivering RE electricity to their customers through electricity rate-based mechanisms, utilities have also entered the field of community solar. In community solar programs, a utility or third-party project developer develops a solar project and sells the output to multiple subscribers who are generally compensated through utility bill credits proportional to the size of their subscription in the project.[86]

Community solar output is often used by utilities to meet RPS compliance obligations, but not always. For instance, in 2016, about 23 thousand customers purchased almost 0.3TWh of community solar output. More than one-tenth – over 0.03TWh came from PG&E (California) "Solar Choice" program, in which subscribers retain RECs by program design, i.e. as a voluntary green purchase.[87]

As of September 2017, there were 223 community solar projects with a total of at least 278MW in operation in the US.[88]

Though these numbers are still relatively modest they are growing fast (Chart 28).

Chart 28: The Rise of Community Solar in the US



Source: NREL, Status and Trends in the U.S. Voluntary Green Power Market (2016 Data)

In addition, of PG&E mentioned above, utility Xcel Energy has been particularly dynamic in the State of Minnesota by delivering well over 200MW of community solar through its "Solar Garden" program. And, as of December 2017, Xcel Energy had another 400MW of "solar garden" projects in the design or construction phase.[89]

Customers' electricity consumption optimization tools and services is the third key area of innovative business models for US electric utilities.

In a market that is heading towards digitalization and integration of large shares of wind and solar power there is an increasing competition to offer a broad range of services to customers, which could both provide flexibility to the electrical system and save electricity customers' money. These services range from off-peak services for space heating, air conditioning and water heating based on off-peak rates, direct load control of water heaters, EV charging management... This is where DR programs, smart meters, smart thermostats, customer-sited solar PV, battery storage, and EV charging stations may play a significant role.

In this field, that is not their traditional business of just selling electricity to the end consumers, but rather to optimize how it is used and/or generated, incumbents are competing and/or partnering with specialized companies like Nest, Sunrun or Tesla.

Regarding DR, US utilities had a significant 33GW potential peak demand savings covered from their retail DR programs in 2015. Among electric utilities already mentioned in this report, Duke Energy, Southern Company, or SCE and Xcel Energy provide such programs to their customers.[90] DR may be a tool to cope with periods of over-generation, or low generation, from wind and solar power by encouraging increasing, or decreasing, electricity consumption, based on electricity prices (which depend on generation levels from VRE).

As an example, to incentivize electricity consumption at specific time, Texas retail company TXU Energy introduced a plan called “Free Nights” which offers free electricity at night coupled with higher daytime rates. This relies on the fact that at night wholesale electricity prices are usually lower than during the day because of higher electricity generation from wind power and lower electricity consumption.[91]

Smart meters and smart thermostats are other products that may help to save consumers’ money and better integrate VRE. By providing a better understanding of electricity consumption patterns, these tools may spur the development of incentives to provide additional flexibility on the demand side.

As for smart meters, which collect customer usage data in intervals of one hour or less, often every 15 minutes, and send it to the utility enabling a better understanding of demand patterns, average penetration rate among residential customers is 41% – with extreme gaps, however. For instance, the three largest Californian electric suppliers PG&E, SDG&E, and SCE have very high rates of residential customers with smart meters installed; 97-100%, while many other utilities’ rate is 0%.[92]

Regarding smart thermostats, some pioneering utilities have entered into partnerships with leading companies. This is the case of NRG Energy, SCE, Exelon’s subsidiary Commonwealth Edison (Illinois), Austin Energy (Texas)…, which have partnered with Nest to provide smart thermostats, which, based on the knowledge of a customer’s schedule and preferences, gradually fine-tune the temperatures in the schedule to help save more energy.[93]

Other pioneering utilities have also entered into partnerships for solar PV installation and battery storage products. This is the case of Exelon’s Constellation which is working with Sunrun for solar PV installation enabling its customers to generate their own green electricity.[94] And of Green Mountain Power (Vermont) (GMP) with Tesla for battery storage, which offers its customers the option to lease a Tesla Powerwall 2.[95]

Finally, some utilities, and particularly California’s three largest electricity suppliers, have advanced ambitious plans to pursue and enable expansion of EVs through massive charging station infrastructure buildout, which would not only increase their electricity sales and revenues, but also add another flexibility option in the management of the grid. For instance, SDG&E targets to build 90,000 residential chargers over a five- to six-year period (limited to 60,000 by the CPUC in March 2018), pilot charging infrastructure builds for medium and heavy-duty vehicles (e.g. delivery trucks, forklifts), and provide incentives for auto dealers and ride-hailing service like Uber and Lyft. This program also aims at directing residential customers towards flexible electricity rates incentivizing charging at night and in the daytime during periods of solar over-generation.[96]

2 Businesses

Across the US, businesses, and especially large customers, are increasingly committing to RE driven by sustainability initiatives and cost-competitiveness of wind and solar power.

Apart from economic (LCOE for generators), political (RPS), and technical (grid integration of VRE) considerations, if US electric utilities are installing gigawatts of wind and solar power and developing a wide range of business offers focusing directly or indirectly on RE this is also because there is an increasing demand from their customers to procure green power.

Among these customers large US businesses have demonstrated strong leadership in recent years. They have done so by making ambitious pledges and taking action to fulfill their commitments. Their engagement may be best crystallized through the "RE100" and "We Are Still In" campaigns and the development of the "Buyers' Principles."

"RE100" is a collaborative, global initiative uniting more than 130 influential businesses (as of 19 June 2018) committed to 100% renewable electricity, working to massively increase demand for – and delivery of – RE. Among them many US companies from various sectors; Apple, Bank of America, Bloomberg, eBay, Facebook, General Motors, Goldman Sachs, Google, Johnson & Johnson, JPMorgan Chase & Co, Kellogg's, Microsoft, Morgan Stanley, Nike, Starbucks, Walmart… (Table 7).[97]

Table 7: Examples of US Companies Committed to Go 100% RE Power

Company Name	Sector	Target year
Apple	Technology	Achieved 2018
Bank of America	Finance	2020
Bloomberg	Financial software, data, and media	2025
eBay	e-commerce	2025
Facebook	Online social media and social networking	Unknown
General Motors	Automobile	2050
Goldman Sachs	Finance	2020
Google	Technology	Achieved 2017
Johnson & Johnson	Medical devices, pharmaceutical and consumers packaged goods	2050
JPMorgan Chase & Co	Finance	2020
Kellogg's	Food	2050
Microsoft	Technology	Achieved 2014
Morgan Stanley	Finance	2022
Nike	Sportswear, equipment and accessories	2025
Starbucks	Coffee	Achieved 2016
Walmart	Retail	Unknown
Wells Fargo	Finance	Achieved 2017

Source: RE100, Companies (as of 19 June 2018)

Publicly launched in July 2014, the "Buyer's Principles" have been developed by a group of large energy buyers to spur progress on RE and to add their perspective to the future of the US energy and electricity system. The "Principles" have been built on an understanding of what customers need, what regulators value, and how utilities have seized these opportunities effectively. There were initially 12 signatories representing about 8TWh of RE demand by 2020, there are now 73 signatories representing over 67TWh of RE annual demand by 2020. Among them; McDonald's (fast food), Marriott International (hospitality), Lockheed Martin (aerospace and defense), Oracle (technology), Staples (office supply retail), Kimberly-Clark (personal care), or PepsiCo (food, snack, and beverage).[98]

And launched in reaction to the announcement by President Trump of the US withdrawal from the Paris Agreement in June 2017, the "We Are Still In" campaign is the broadest cross-section of the US economy ever assembled in pursuit of climate action. And out of the more than 2,700 organizations part of this campaign, over 1,900 are businesses and investors (as of 19 June 2018) continuing to support climate action to meet the Paris agreement.[99]

This irreversible movement is based on two decisive factors; sustainability on economics. Engaged businesses want to limit the impact of their operations on the environment and do it in a cost-efficient, which cost-competitive wind and solar power make possible.

In order to meet their commitments, businesses have a number of options at their disposal. Beyond those explored in the previous section of this report, which are based on procuring RE electricity from power supplying companies, businesses can leverage two additional mechanisms; unbundled RECs and PPAs.

Businesses can buy RECs separated or "unbundled" from the underlying electricity from REC providers. As companies start to investigating RE purchasing options, they often begin with an unbundled REC purchase, as the purchase has low transaction costs, does not require a long-term commitment, and is straightforward compared to an off-site PPA or participation in a green tariff.[100]

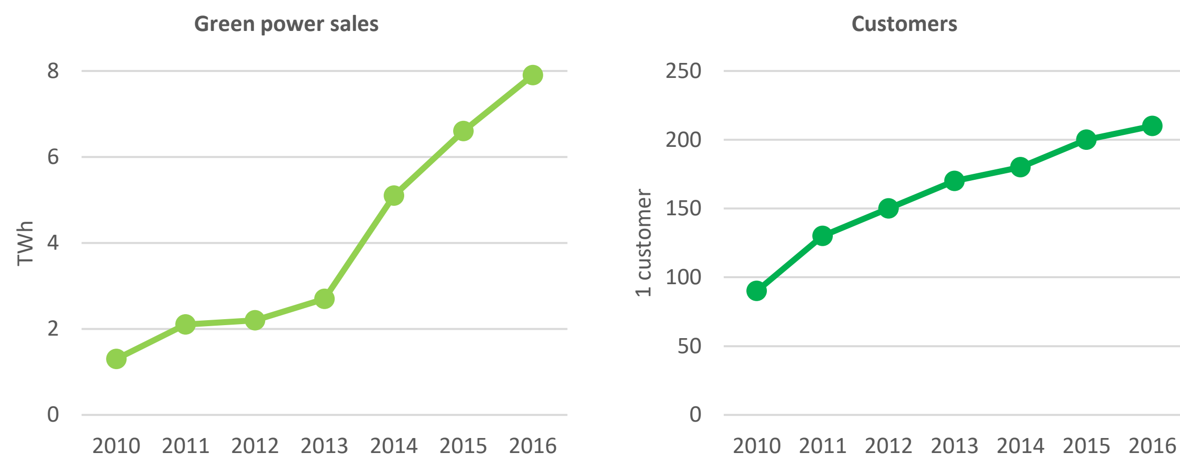
In addition, businesses can also procure green power through a PPA that is a long-term contract with an on- or off-site RE project. There are two main forms of PPAs; physical and financial.[101]

In a physical PPA, the customer enters into a contract to buy electricity at a negotiated PPA rate. And the purchased electricity is credited towards the customer's electric demand such that, from a billing perspective, the customer uses the electricity (regardless of whether the electricity is physically consumed at the customer's site).[102]

In a financial (or virtual) PPA, the customer enters into a contract for differences for electricity at a negotiated PPA rate. Electricity generated is fed into the local grid and sold at the local wholesale rate. If the wholesale rate is lower than the PPA rate, the customer pays the difference to the generator and vice versa. The generator output is not credited towards the customer's electricity use. RECs are received by the customer from the generator.[103]

The PPA market, which is dominated by large non-residential customers, is expanding fast; from 1.3TWh and below 100 customers in 2010 to almost 8TWh and over 200 customers in 2016 (Chart 29 on next page).

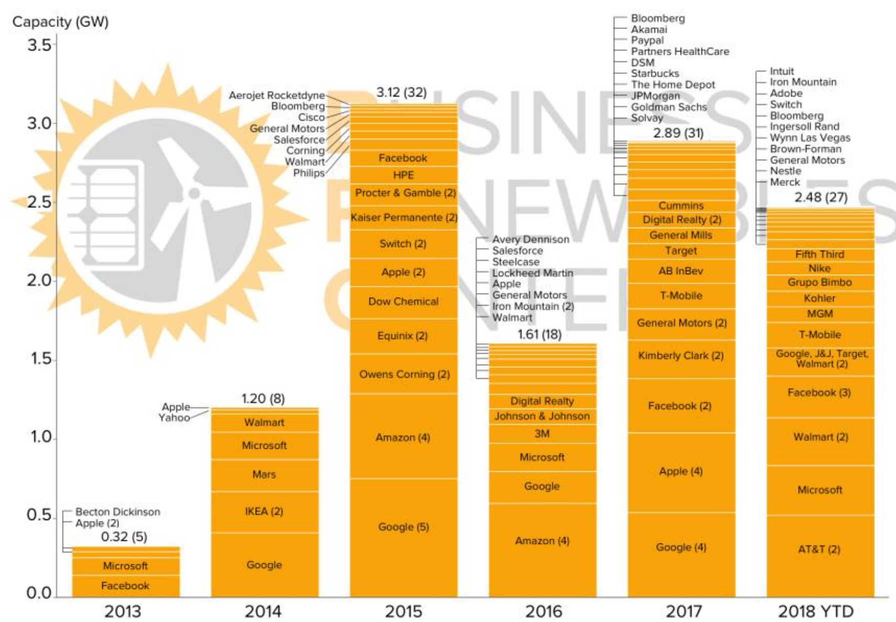
Chart 29: US Large Businesses Driving the Growth of PPAs to Fulfill their RE Commitments



Source: NREL, Status and Trends in the U.S. Voluntary Green Power Market (2016 Data)

The combination of these trends has resulted in substantial results. According to RMI's Business Renewables Center, announced corporate RE deals, which include PPAs, green power purchases, green tariffs, and outright project ownership, reached almost 12GW in the US since 2013 (Chart 30).

Chart 30: Announced Corporate RE Deals in the US 2013-2018 (through May)



Note: Excludes on-site generation and deals with operating plants. (#) indicates number of deals each year by individual companies

Source: RMI Business Renewables Center, BRC Deal Tracker (accessed 19 June 2018)

Among the leaders were Google, Amazon, Microsoft, Apple, and Facebook. And their favorite technologies to invest in, without surprise, wind and solar power.[104]

3 States, cities, communities, and households

Local political authorities and social pioneers are all importantly contributing – each at their own scale – to the successful deployment of RE across the US.

Due to the particularity of the US political system, i.e. a federation of States, States are relatively autonomous and powerful. Thus, the role of State level policymakers in defining the visions for their State in terms of RE expansion and enacting supportive policies to turn these visions into reality, is critical. In "I 3 The US as a patchwork," States RPS have been presented and their importance underlined. Another State level policy, which has been effective in promoting RE in the US is net metering.

Net metering policies enable customers to use the electricity they generate from distributed RE (e.g rooftop solar PV) in excess of their consumption at certain times to offset their use of electricity from the grid at other times.[105]

At the end of 2017, net metering policies existed in a very large majority of US States, including for examples; Texas (voluntary utility policies), Florida, California, Pennsylvania, Illinois, and New York (all State-developed mandatory rules for certain utilities).[106]

Net metering is particularly popular in California where more than 90% of all megawatts of customer-sited solar capacity interconnected to the grid in the three large investor-owned utilities territories (PG&E, SCE, and SDG&E) are on net metering tariffs. Under these tariffs, participating customers receive monthly bill credits for excess generation at the same retail rate (including generation, transmission, and distribution) that the customer would have paid for electricity consumption according to their otherwise applicable rate structure.[107]

At a more local level, cities also have the power to lead RE progresses. In this regard, US leading cities of very different sizes are currently targeting to reach 100% RE electricity, and at least a couple of them have already achieved it; Burlington (Vermont) in 2014 and Greensburg (Kansas) in 2015 (Table 8).

Table 8: Examples of US Cities Targeting 100% RE Electricity

City	State	Target year
Burlington	Vermont	Achieved 2014
Greensburg	Kansas	Achieved 2015
Minneapolis	Minnesota	2030
Orlando	Florida	2050
Pittsburgh	Pennsylvania	2035
Saint Louis	Missouri	2035
Salt Lake City	Utah	2032
San Diego	California	2035
San Francisco	California	2030
Seattle	Washington	Unknown

Source: REN21, Renewables Global Status Report 2018

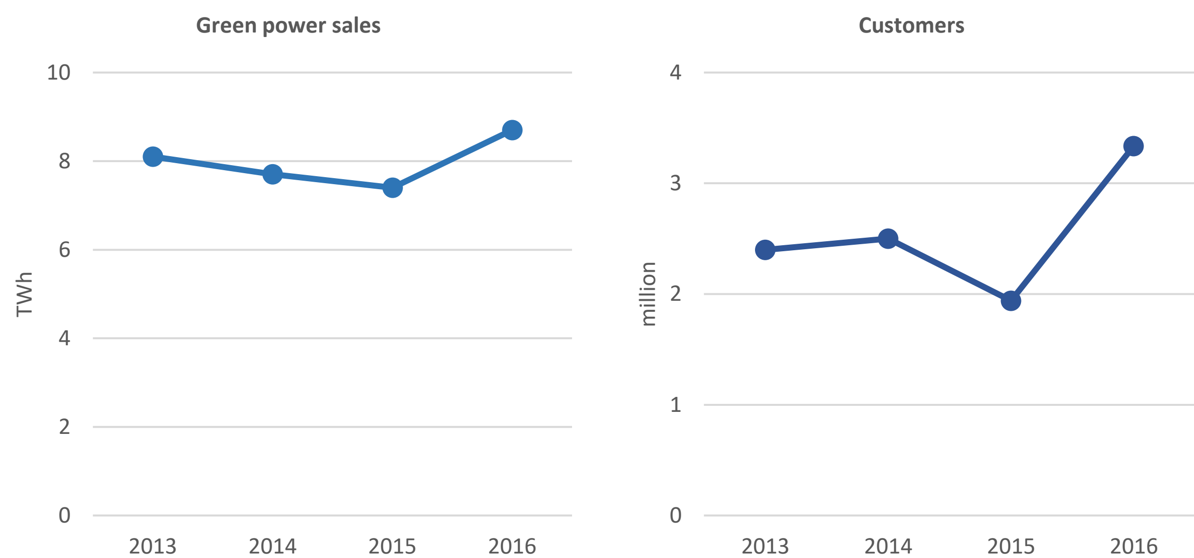
Less ambitious, but also moving forward are cities like Los Angeles (California) and New York (New York), which have set technology specific capacity deployment target for solar power. Specifically, Los Angeles and New York aim for 1.3GW and 1GW, respectively, of solar capacity both by 2020.[108]

Local governments may also help engaging normal people in the expansion of RE by creating frameworks enabling communities to take action.

For instance, some communities in the US can aggregate their loads to collectively procure green power as a bulk purchaser through an alternative electricity supplier. That is called "community choice aggregation" (CCA). CCA provides customer choice, reduced energy costs by aggregating purchasing power and creating large contracts with generators (something an isolated small customer is unable to do), RE (possibly locally generated), and environmental benefits. Electric utilities remain responsible for transmission and distribution. This possibility is, however, not available everywhere – as of 2017, seven States (including California, Illinois, Massachusetts, New York, and Ohio among others) had passed legislation allowing certain jurisdictions to form CCAs.[109]

Participation in this type of programs increased by about 1 million customers between 2013 and 2016, which is remarkable. However, this has not necessarily resulted in a significant growth of green power sales; "only" +0.6TWh in this period (Chart 31).

Chart 31: US CCAs Attracting more Customers



Source: NREL, [Status and Trends in the U.S. Voluntary Green Power Market (2016 Data)]

With approximately 5TWh of green power sales, 2 million of customers, and 62 programs in 2016, CCA was particularly popular in Illinois, around Chicago notably.

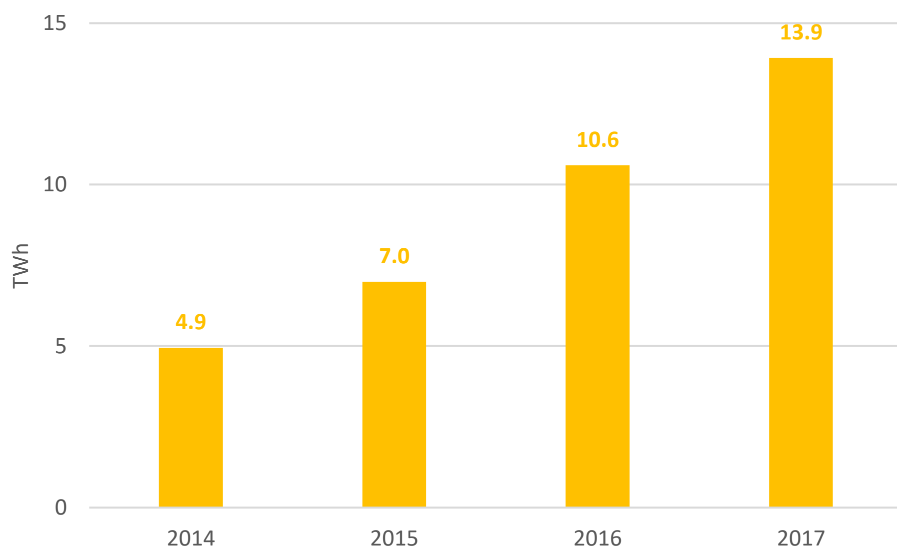
In 2016, CCA growth, both in terms of green power sales and number of customers, has been especially rapid in California. These increases were mainly driven by two programs; CleanPowerSF (San Francisco) – rolled out in May 2016, and Marin Clean Energy (Marin and Napa counties, unincorporated Contra Costa county, and over ten cities) – expanded to new territories, which provide higher RE content at competitive prices compared with electric utility PG&E's offers.[110]

Finally, last but not least, all the households who make the decision to either install their own RE generation system (e.g. rooftop PV) or to subscribe to one of the various green power programs to cover all or part of their electricity consumption are also leaders contributing to the "US Other Revolution."

Their decision to install rooftop PV may be motivated by a number of reasons including cheaper electricity – socket parity having been reached in many US States, sustainability or independency from the grid.[111]

Households are obviously not installing gigawatts in their garden, but aggregated their efforts are quickly making a big difference. Indeed, following a few years of rapid deployment electricity generation from residential solar PV reached about 14TWh in 2017 (Chart 32). That is roughly a doubling from 2015 and almost a tripling from 2014. That is also almost three times more than the electricity supplied from the US latest new build nuclear reactor Watts Bar 2 (capacity of about 1.2GW) in 2017.[112]

Chart 32: Electricity Generation from Residential Solar PV in the US 2014-2017



Source: US EIA, Annual Electricity Report 2015-2016 and Monthly Electricity Report February 2018

CONCLUSION

The US is now successfully massively deploying wind and solar power. Progresses in key States such as California and Texas are particularly remarkable.

These developments come with a number of benefits; very affordable electricity rates, creation of hundred thousand jobs, and cleaner air.

They are also associated with a number of challenges; grid integration of VRE, market integration of close to zero marginal cost RE, and keeping track of RE electricity. Yet, none of these challenges have proven insurmountable so far, except for uncompetitive, inflexible, and dirty coal and nuclear power.

The “other revolution” is not only driven by economic and technological progresses on the supply side, it is also pushed forward by American leaders in all sectors of the economy. From electric utilities, to businesses, local political authorities and social pioneers.

Finally, President Trumps’ election raised concerns that RE growth may be jeopardized in the US. These are probably largely unfounded, as in 2017 for the first year of its mandate RE reached record heights. This is a symbol that efforts to resist the ongoing revolution will be vain, RE expansion being now unstoppable.

Appendix A: Ranking of US States Total Electricity Generation 2017 (*Source: US EIA, Monthly Electricity Report February 2018*)

Rank	State	TWh
1	Texas	452.9
2	Florida	238.1
3	California	216.7
4	Pennsylvania	200.6
5	Illinois	182.0
6	Alabama	139.2
7	North Carolina	130.9
8	Georgia	129.2
9	New York	129.1
10	Ohio	119.1
11	Washington	115.6
12	Michigan	112.5
13	Arizona	107.6
14	Indiana	100.5
15	Louisiana	97.2
16	South Carolina	93.6
17	Virginia	93.6
18	Missouri	84.0
19	Tennessee	78.2
20	Oklahoma	76.6
21	New Jersey	76.2
22	West Virginia	73.4
23	Kentucky	72.1
24	Wisconsin	65.3
25	Arkansas	62.1
26	Mississippi	60.6
27	Minnesota	59.8
28	Oregon	58.7
29	Iowa	56.6
30	Colorado	54.8
31	Kansas	51.4
32	Wyoming	46.8
33	North Dakota	40.9
34	Nevada	38.4
35	Utah	37.0
36	Nebraska	35.9
37	Maryland	34.9
38	Connecticut	34.5
39	New Mexico	33.8
40	Massachusetts	33.0

Rank	State	TWh
41	Montana	28.3
42	New Hampshire	17.6
43	Idaho	15.9
44	Maine	11.2
45	Hawaii	10.8
46	South Dakota	10.5
47	Delaware	7.8
48	Alaska	6.0
49	Rhode Island	5.3
50	Vermont	2.2

Appendix B: List of US States Abbreviations

State	Abbreviation
Alabama	AL
Alaska	AK
Arizona	AZ
Arkansas	AR
California	CA
Colorado	CO
Connecticut	CT
Delaware	DE
Florida	FL
Georgia	GA
Hawaii	HI
Idaho	ID
Illinois	IL
Indiana	IN
Iowa	IA
Kansas	KS
Kentucky	KY
Louisiana	LA
Maine	ME
Maryland	MD
Massachusetts	MA
Michigan	MI
Minnesota	MN
Mississippi	MS
Missouri	MO
Montana	MT
Nebraska	NE
Nevada	NV
New Hampshire	NH
New Jersey	NJ
New Mexico	NM
New York	NY
North Carolina	NC
North Dakota	ND
Ohio	OH
Oklahoma	OK
Oregon	OR
Pennsylvania	PA
Rhode Island	RI
South Carolina	SC

State	Abbreviation
South Dakota	SD
Tennessee	TN
Texas	TX
Utah	UT
Vermont	VT
Virginia	VA
Washington	WA
West Virginia	WV
Wisconsin	WI
Wyoming	WY

Appendix C: State RPS Eligible RE Technologies (*Source: Database of State Incentives for Renewables & Efficiency, Renewable Portfolio Standard for each State (accessed 13 June 2018)*)

State	RPS Eligible RE Technologies for Electricity Generation
Arizona	Hydro, biomass, geothermal, wind, solar photovoltaic, solar thermal, fuel cells using renewable fuels, landfill gas, anaerobic digestion, municipal solid waste, and combined heat & power
California	Small hydro (up to 30MW), biomass, geothermal, wind, solar photovoltaic, solar thermal, ocean, tidal, wave, fuel cells using renewable fuels, landfill gas, anaerobic digestion, and municipal solid waste
Colorado	Small hydro (up to 30MW), biomass, geothermal, wind, solar photovoltaic, solar thermal, fuel cells using renewable fuels, landfill gas, anaerobic digestion, municipal solid waste, and coal mine methane (if the Public Utilities Commission determines it is a greenhouse gas neutral technology)
Connecticut	Hydro, biomass, geothermal, wind, solar photovoltaic, solar thermal, ocean, tidal, wave, fuel cells, landfill gas, anaerobic digestion, municipal solid waste, and combined heat & power
Delaware	Small hydro (up to 30MW), biomass, geothermal, wind, solar photovoltaic, solar thermal, ocean, tidal, wave, fuel cells using renewable fuels, landfill gas, and anaerobic digestion
Hawaii	Hydro, biomass, geothermal, wind, solar photovoltaic, solar thermal, ocean, tidal, wave, fuel cells using renewable fuels, landfill gas, anaerobic digestion, municipal solid waste, and combined heat & power
Illinois	Hydro, biomass, wind, solar photovoltaic, solar thermal, landfill gas, and anaerobic digestion
Iowa	Small hydro (no explicit limit), biomass, wind, solar photovoltaic, solar thermal, landfill gas, anaerobic digestion, and municipal solid waste
Maine	Hydro, biomass, geothermal, wind, solar photovoltaic, solar thermal, tidal, fuel cells, landfill gas, municipal solid waste, and combined heat & power
Maryland	Hydro, biomass, geothermal, wind, solar photovoltaic, solar thermal, ocean, tidal, wave, fuel cells using renewable fuels, landfill gas, anaerobic digestion, and municipal solid waste
Massachusetts	Hydro, biomass, geothermal, wind, solar photovoltaic, solar thermal, ocean, tidal, wave, fuel cells using renewable fuels, landfill gas, anaerobic digestion, and municipal solid waste
Michigan	Hydro, biomass, geothermal, wind, solar photovoltaic, solar thermal, tidal, wave, landfill gas, anaerobic digestion, and municipal solid waste
Minnesota	Small hydro (up to 100MW), biomass, wind, solar photovoltaic, solar thermal, landfill gas, anaerobic digestion, municipal solid waste, hydrogen generated by another eligible renewable energy, and co-firing
Missouri	Small hydro (up to 10MW), biomass, wind, solar photovoltaic, solar thermal, fuel cells using renewable fuels, landfill gas, anaerobic digestion, municipal solid waste, and co-firing
Montana	Small hydro (up to 15MW), biomass, geothermal, wind, solar photovoltaic, solar thermal, fuel cells using renewable fuels, landfill gas, anaerobic digestion, and energy storage technologies based upon the portion of electricity produced that is attributable to renewable sources
Nevada	Hydro, biomass, geothermal, wind, solar photovoltaic, solar thermal, landfill gas, anaerobic digestion, and municipal solid waste
New Hampshire	Hydro, biomass, wind, solar photovoltaic, solar thermal, ocean, tidal, wave, fuel cells using renewable fuels, landfill gas, anaerobic digestion, municipal solid waste, combined heat & power, and hydrogen from biomass fuels or landfill gas
New Jersey	Small hydro (up to 30MW), biomass, geothermal, wind, solar photovoltaic, solar thermal, ocean, tidal, wave, fuel cells, landfill gas, and anaerobic digestion
New Mexico	Hydro, biomass, geothermal, wind, solar photovoltaic, solar thermal, fuel cells using renewable fuels zero emission technology, landfill gas, and anaerobic digestion
New York	Hydro, biomass, wind, solar photovoltaic, ocean, tidal, wave, fuel cells, landfill gas, anaerobic digestion, and combined heat & power

North Carolina	Hydro, biomass, geothermal, wind, solar photovoltaic, solar thermal, ocean, tidal, wave, landfill gas, anaerobic digestion, combined heat & power, and hydrogen derived from renewables
Ohio	Hydro, biomass, geothermal, wind, solar photovoltaic, solar thermal, fuel cells, landfill gas, anaerobic digestion, municipal solid waste, and combined heat & power
Oregon	Hydro, biomass, geothermal, wind, solar photovoltaic, solar thermal, ocean, tidal, wave, landfill gas, anaerobic digestion, municipal solid waste, combined heat & power, and hydrogen
Pennsylvania	Hydro, biomass, geothermal, wind, solar photovoltaic, solar thermal, fuel cells, landfill gas, anaerobic digestion, municipal solid waste, and combined heat & power
Rhode Island	Small hydro (up to 30MW), biomass, geothermal, wind, solar photovoltaic, solar thermal, ocean, tidal, wave, fuel cells using renewable fuels, landfill gas, and anaerobic digestion
Texas	Hydro, biomass, geothermal, wind, solar photovoltaic, solar thermal, ocean, tidal, wave, and landfill gas
Vermont	Hydro, biomass, geothermal, wind, solar photovoltaic, solar thermal, tidal, wave, fuel cells using renewable fuels, landfill gas, anaerobic digestion, and combined heat & power
Washington	Hydro, biomass, geothermal, wind, solar photovoltaic, solar thermal, ocean, tidal, wave, landfill gas, and anaerobic digestion
Wisconsin	Hydro, biomass, geothermal, wind, solar photovoltaic, solar thermal, tidal, wave, fuel cells using renewable fuels, landfill gas, anaerobic digestion, municipal solid waste, and combined heat & power

Appendix D: List of Abbreviations

AB: Assembly Bill
BHE: Berkshire Hathaway Energy
BNEF: Bloomberg New Energy Finance
CAISO: California Independent System Operator
CCA: community choice aggregation
CCGT: combined cycle gas turbine
CO_2: carbon dioxide
CPP: Clean Power Plan
CPUC: California Public Utilities Commission
CREZ: Competitive Renewable Energy Zones
CSS: Customer Self-Supply
DR: demand response
EFH: Energy Future Holdings
EFI: Energy Futures Initiative
EIM: Energy Imbalance Market
ERCOT: Electric Reliability Council of Texas
ESR: electricity system reform
ETNNA: Environmental Tracking Network of North America
FE: FirstEnergy
FERC: Federal Energy Regulatory Commission
FiT: feed-in tariff
GHG: greenhouse gas
GMP: Green Mountain Power
GW: gigawatt
GWEC: Global Wind Energy Council
HECO: Hawaiian Electric Company
IAEA: International Atomic Energy Agency
IEA PVPS: International Energy Agency Photovoltaic Power Systems Program
IEA: International Energy Agency
ISO: independent system operator
ITO: independent transmission operator
kW: kilowatt
kWh: kilowatt-hour
LBNL: Lawrence Berkeley National Laboratory
LCOE: levelized cost of electricity
MISO: Midcontinent Independent System Operator
MW: megawatt
MWh: megawatt-hour
NASEO: National Association of State Energy Officials
NERC: North American Electric Reliability Corporation
NRC: Nuclear Regulatory Commission
NREL: National Renewable Energy Laboratory
OCGT: open cycle gas turbine
PG&E: Pacific Gas and Electric
PPA: power purchase agreement
PURPA: Public Utility Regulatory Policies Act
PV: photovoltaic
RE: renewable energy
REC: renewable energy certificate
REI: Renewable Energy Institute
REN21: Renewable Energy Policy Network for the 21st Century
RMI: Rocky Mountain Institute
RPS: renewable portfolio standard
RTO: regional transmission operator
SCE: Southern California Edison
SDG&E: San Diego Gas and Electric
SGIP: Self-Generation Incentive Program
SPP: Southwest Power Pool
TEPCO: Tokyo Electric Power Company
TSO: transmission system operator
TWh: terawatt-hour
US DOE: United States Department of Energy
US EIA: United States Energy Information Administration
US EPA: United States Environmental Protection Agency
US: United States
VRE: variable renewable energy

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