Informing the **Transmission Discussion**

A Look at Renewables Integration and Resilience Issues for Power Transmission in Selected Regions of the United States

January 2020

Industry Backdrop

Contents

Major Trends in the Electric Industry

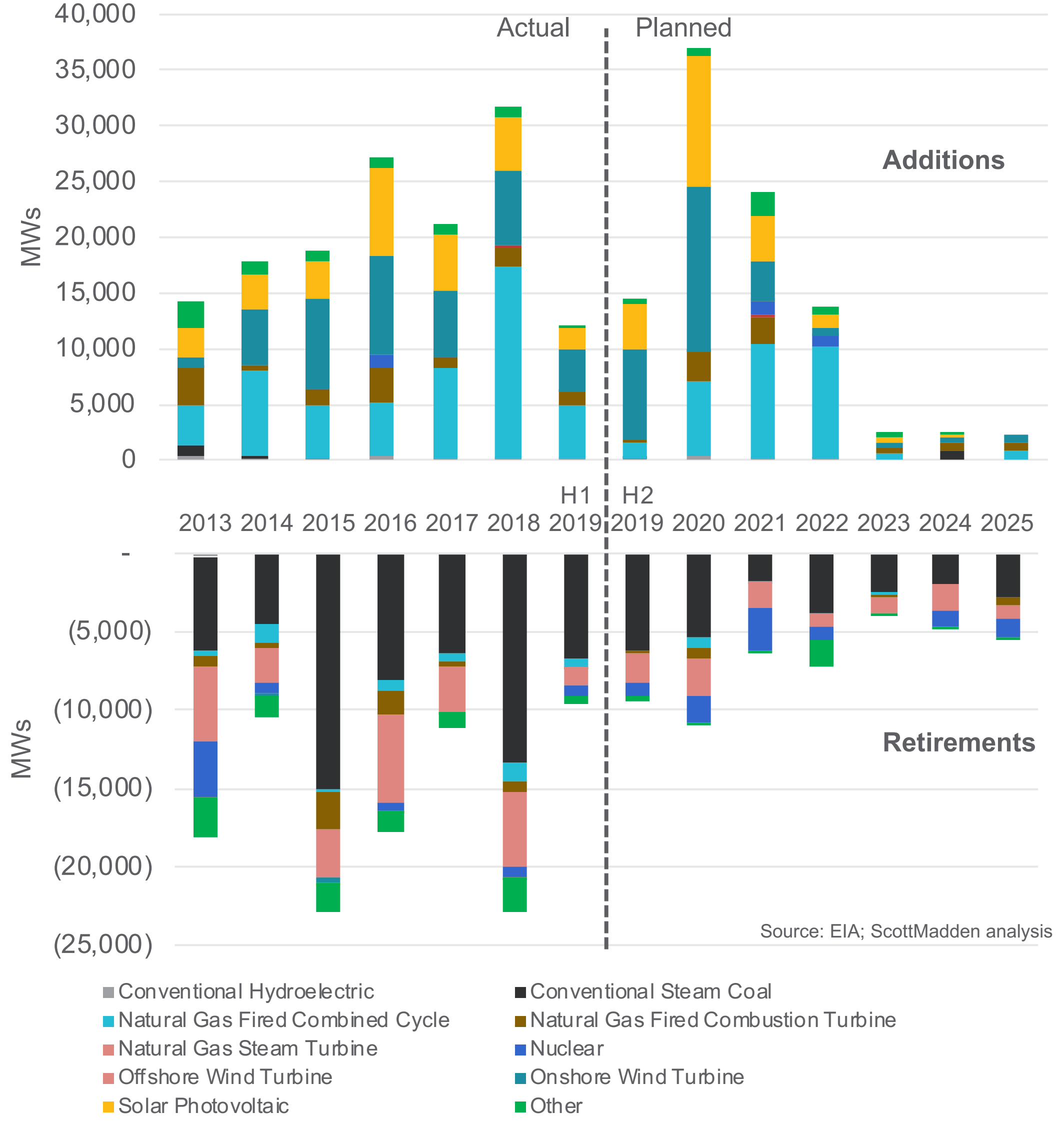
- The electric industry has undergone a tremendous amount of growth and change over the past [20] years, and it continues to evolve as policy and customer preferences, improving technology costs, and increasing focus on reducing greenhouse gas emissions (GHG) drive shifts in energy resources and consumption patterns.
- In particular, the electric industry is undergoing a gradual transformation driven by four key developments:
  - **A changing energy mix:** Abundant and inexpensive natural gas, in large part enabled by hydraulic fracturing, has increased the attractiveness of development of gas-fired power generation. The economics of gas generation has also worked to displace and force retirement of older coal-fired and, in some areas, emissions-free nuclear generation. In addition, growing amounts of utility-scale wind and solar generation are being proposed across the country, but their output capability and economic viability is highly location-dependent.
  - **Deployment of distributed energy resources (DERs) and energy storage:** The Midcontinent ISO (MISO) terms this trend as decentralization. The growth in smaller energy resources on the distribution system, whether behind-the-meter (rooftop solar, storage, and demand response) or larger distributed generation and storage interconnected at the distribution level (including microgrids), continues; as interest grows, costs for those resources decline, and policy support and favorable benefit-cost analysis warrants their consideration. While these resources may support local reliability and resiliency, the bulk power system may lack visibility and control of these resources, creating planning and operating challenges.
  - **Aspirations for beneficial electrification:** Consumers are interested in emissions reduction and decarbonization, and utilities are interested in growing load (to improve load factor) and displacing carbon-intensive applications with energy from a less carbon-intensive resource mix. As a result, utilities and policymakers are investigating electrification of a number of activities that traditionally use other fuels, such as space heating and particularly light- and heavy-duty vehicles. While this can provide some incremental load growth, absent price and other incentives, electrification may affect the level, growth, and patterns of electricity demand in ways we cannot yet determine.
  - **Strong interest in renewable and other GHG emissions-free resources:** While renewable portfolio standards (RPS) have been in place in a number of jurisdictions for years, more states and utilities have established or increased clean energy goals on an ambitious pace, acting in the absence of federal policy. Supplementing this is continued interest by large corporate buyers in renewable energy. All of this may provide tailwinds for further development of renewable resources to meet this demand.
- Overlaying these trends is concern, in some minds urgent, about the resilience of the U.S. electric system to cyber security and physical threats, as well as extreme weather-related threats to power infrastructure from direct damage, fuel availability issues, and grid flexibility during times of system stress.

Trend: A Changing Energy Mix

Conventional Capacity Retiring and New Gas-Fired Capacity Coming Online

- **Shift to gas:** The electric system has long relied on large, dispatchable units located relatively near load centers. However, as those units have aged and natural gas prices have made it more attractive as a fuel, they are being replaced with gas-fired units, not necessarily close to load. Many of those units have an advantage of being flexible for ramping duties, an important characteristic with more variable energy (discussed later).
- **Conventional capacity retirements:** NERC estimates that approximately 39 GWs of coal-fired, 13 GWs of natural gas-fired, and 1.1 GWs of nuclear power capacity have retired since 2013. It also notes the announced retirement of nearly 27 GWs (9 GWs coal-fired, 7 GWs of nuclear, and 10.9 GWs of gas-fired generation) through 2028. Another estimate by Bloomberg totaled 35 GWs of announced coal capacity to retire between 2019 and 2025.
- **Watching potential resilience and reliability impacts:** Increased reliance on natural gas may have reliability and resilience effects. Some regions currently have significant penetration of natural gas capacity as a percentage of total capacity. More than 50% of capacity in California, Texas, Florida, New England, and the Desert Southwest, for example, is natural gas-fired. Industry and regulators continue to examine fuel assurance and the impact of potential gas disruptions.
- **Reconfiguring the grid:** NERC has noted that capacity retirements near large load centers with limited transmission import capability pose the greatest potential risk to reliability, unless replaced with plants in the same vicinity. Voltage issues could arise with increased imports, and reliability coordinators and system operators are analyzing these potential impacts as units retire.
- **More variable energy resources are entering the mix, and many of the dispatchable resources historically located near load are being retired and, in some cases, being replaced by gas-fired capacity.**

U.S. Power Plant Additions and Planned Additions (in Net Summer MWs)



Source: EIA; ScottMadden analysis

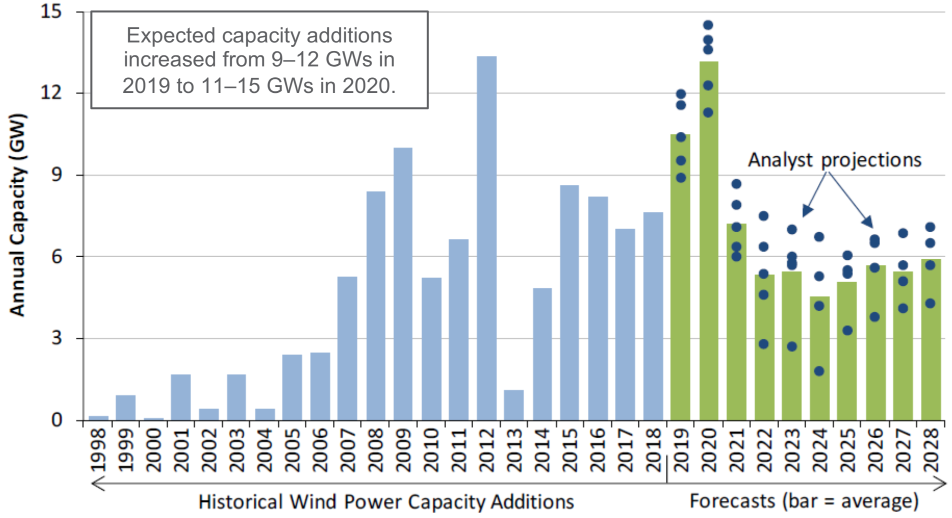
Sources: NERC, 2018 Long-Term Reliability Assessment (Dec. 2018); Bloomberg New Energy Finance/Business Council for Sustainable Energy, 2019 Sustainable Energy in America Factbook (Feb. 2019).

Trend: A Changing Energy Mix (Cont'd)

Growing Renewable Resources

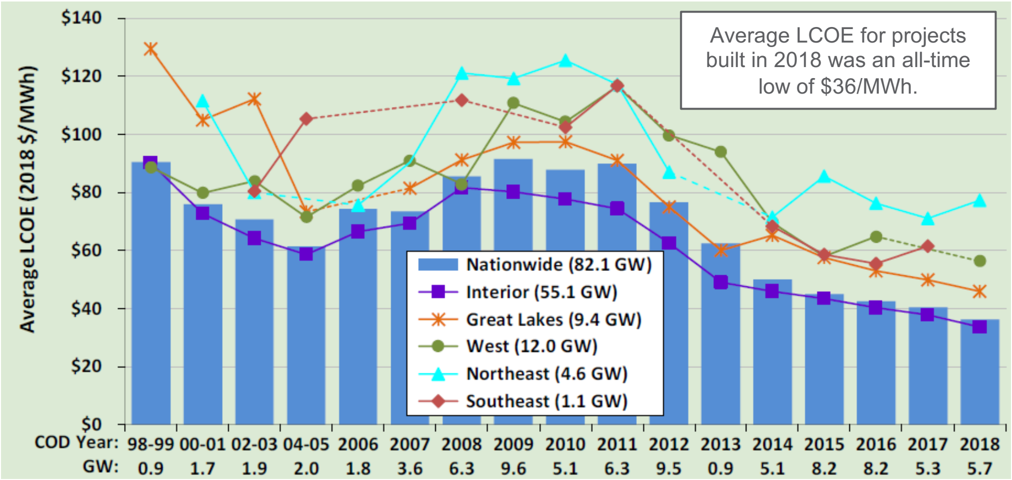
- **Utility-scale growing:** There are significant amounts of renewable resources—principally utility-scale wind and solar generation—expected to be built over the next several years and beyond. In addition to customer and policy preferences (discussed elsewhere), improving installed and levelized costs have made these resources more attractive.
- **Wind additions:** Cumulative wind capacity is more than 96 GWs in the United States. According to the Department of Energy (DOE), wind comprised 28% of all U.S. capacity additions over the last decade and an even larger fraction of new capacity in the Interior (56%) and Great Lakes (40%) regions. Its contribution to generation capacity growth over the last decade is somewhat smaller in the West (18%) and Northeast (13%) and considerably less in the Southeast (1%). A key uncertainty for wind power is whether the federal production tax credit is extended beyond its current final "under construction" year of 2019, as shown in the spike in expected additions in 2019–2020 (below left). As stated by the DOE, "expectations for continued low natural gas prices and modest growth in electricity demand also put a damper on [wind capacity] growth expectations, as do limited transmission infrastructure and competition from other resources (natural gas and—increasingly—solar, in particular) in certain regions of the country."

Wind Power Capacity Additions: Historical Installations and Projected Growth



Source: DOE

Generation-Weighted Average Wind Levelized Cost of Energy (1998–2018): National and Regional



Source: DOE

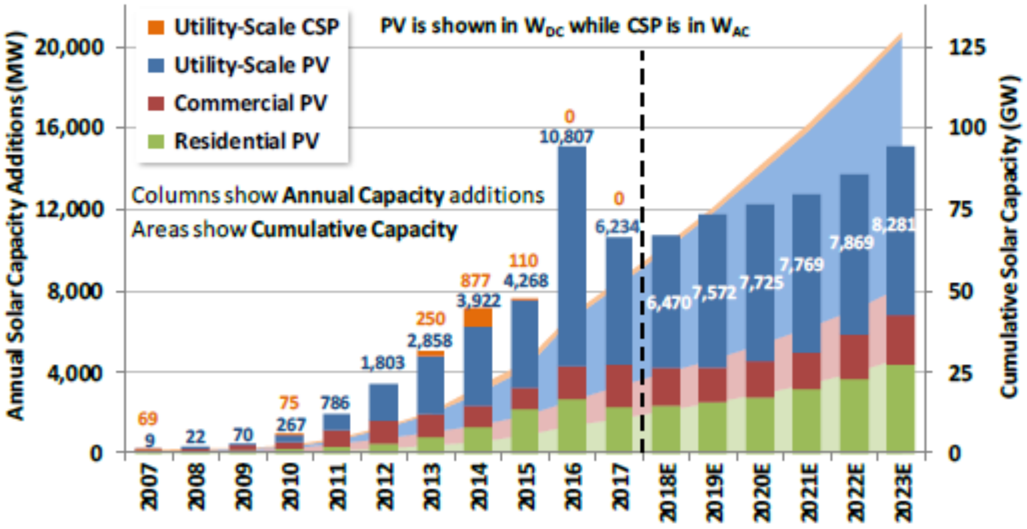
Source: DOE, 2018 Wind Technologies Report (Aug. 2019)

Trend: A Changing Energy Mix (Cont’d)

Growing Renewable Resources (Cont’d)

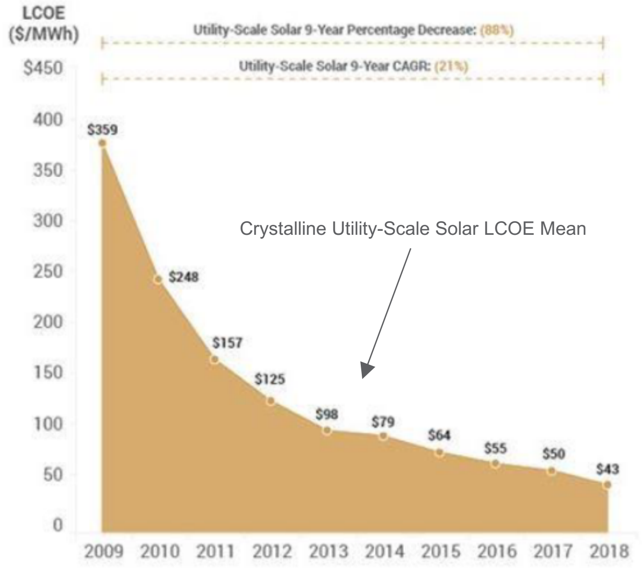
- **Solar’s recent gains:** Solar has recently emerged as the second-largest increment of new generation capacity, behind gas and ahead of utility-scale wind. Wind capacity, however, totaled about 98 GWs in 2018, roughly equal to nuclear power in terms of carbon emissions-free generating capacity. As of year end 2018, installed solar capacity totaled 65 GWs, with utility-scale solar photovoltaic (PV) capacity comprising about 39 GWdc (about 33 GWac).
- **More solar coming:** According to Wood Mackenzie and the Solar Energy Industries Association, there is nearly 2.5 times the existing utility-scale PV capacity in the development pipeline, with nearly 38 GWdc contracted (8.6 GWdc of that under construction) and more than 56 GWdc announced.

Solar Capacity Additions: Historical Installations and Projected Growth



Source: LBNL

Reduction in Solar Levelized Cost of Energy: Down 88% Since 2009



Source: ACORE (citing Lazard)

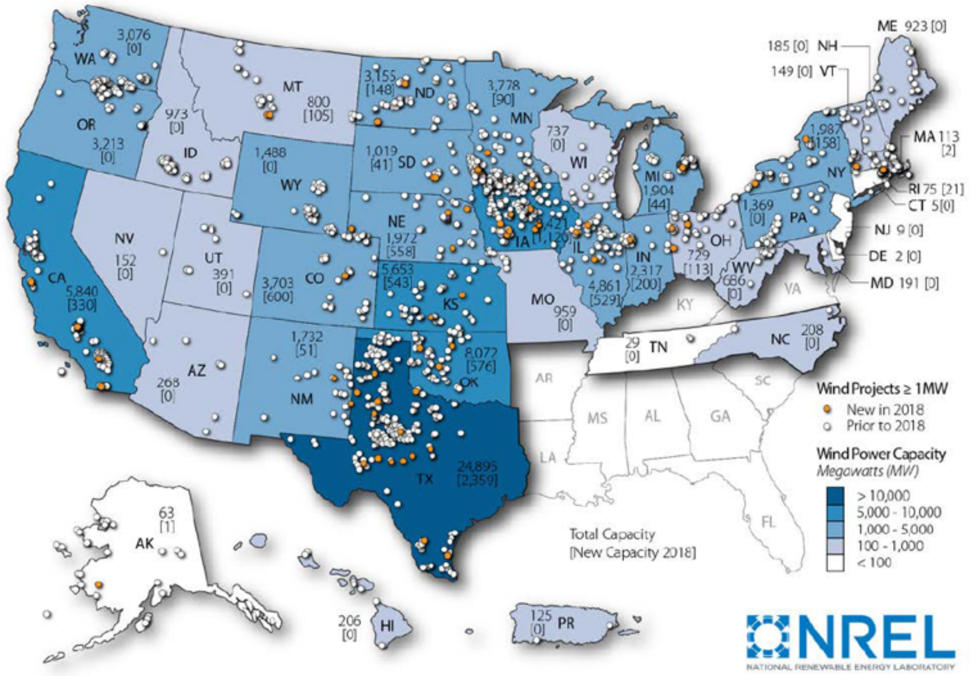
Sources: Bloomberg New Energy Finance/Business Council for Sustainable Energy, 2019 Sustainable Energy in America Factbook (Feb. 2019); American Council on Renewable Energy, Renewable Energy: U.S. Trends and Drivers (Apr. 11, 2019); SEIA/Wood Mackenzie, Solar Market Insight Report 2019 Q3 (Sept. 2019); Lawrence Berkeley Nat’l Lab, Utility-Scale Solar: Empirical Trends in Project Technology, Cost, Performance, and PPA Pricing in the United States (Sept. 2018)

Trend: A Changing Energy Mix (Cont'd)

Location Matters

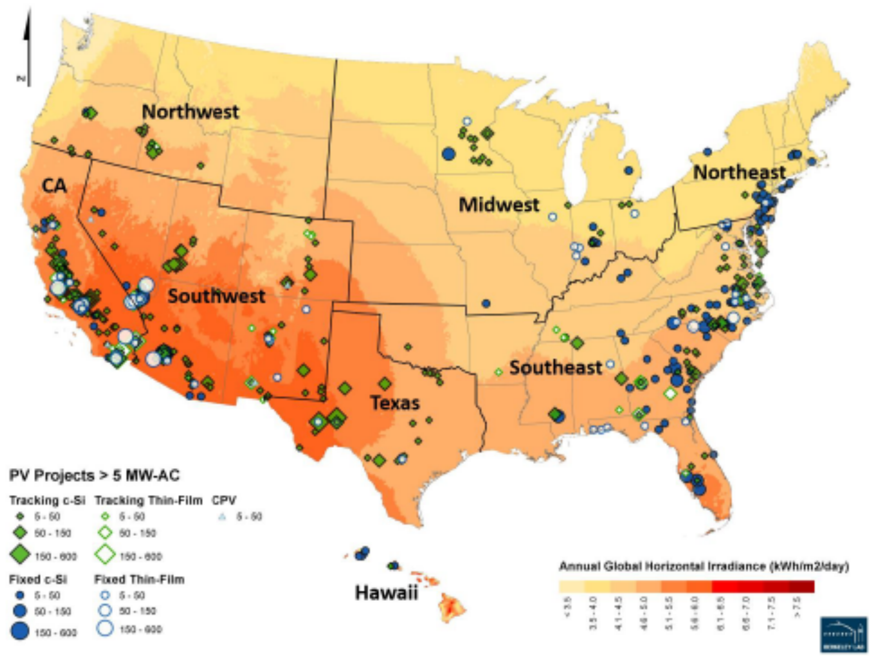
- **Resources dictate location:** Wind and solar potential is dependent upon the available resource potential. Thus, wind speeds and solar irradiance dictate, in large part, the location for development of these resources. In some cases, there is an overlap of the resources (e.g., the Texas Panhandle), but as the maps below show, recent development of these respective resources is concentrated in different regions.
- **Solar vs. wind:** Solar has been concentrated in California, the Southwest, Texas, and increasingly in the Southeast. Wind has historically been concentrated in the Plains, upper Midwest (including around the Great Lakes), and Texas, although increasing development is occurring in the Mountain West, New York, and New England.

Location Of Wind Power Development in the United States (2018)



Source: NREL

Global Horizontal Irradiance (GHI) and Utility-Scale PV Projects (2018)



Source: DOE

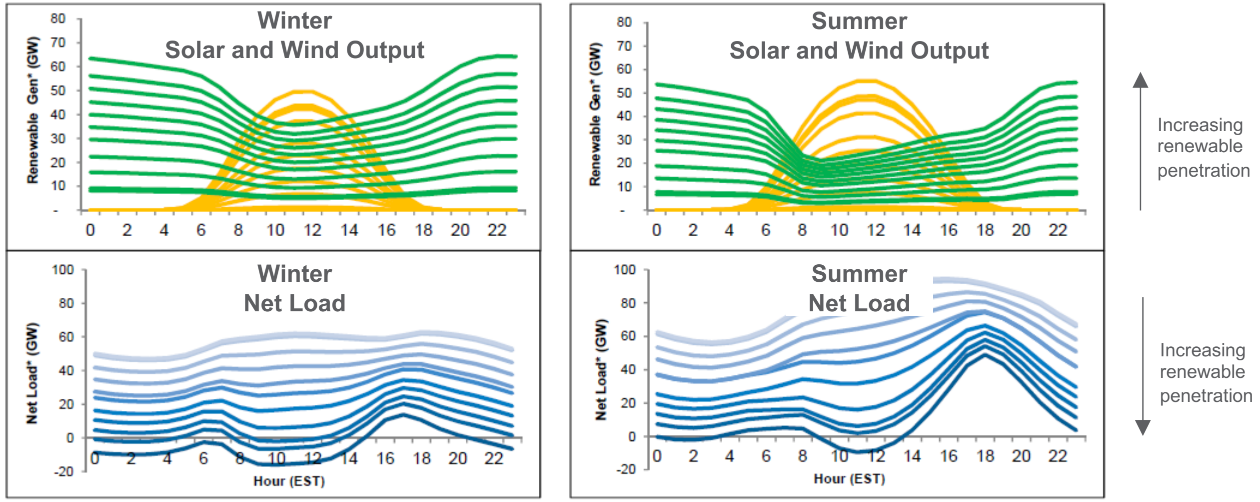
Source: DOE, 2018 Wind Technologies Report (Aug. 2019); Lawrence Berkeley Nat'l Lab, Utility-Scale Solar: Empirical Trends in Project Technology, Cost, Performance, and PPA Pricing in the United States (Sept. 2018); AWEA, U.S. Wind Industry Annual Market Report 2018 (Aug. 2019)

Trend: A Changing Energy Mix (Cont'd)

Different Operating Profile

- **New issues:** With the introduction of growing amounts of renewable resources, policymakers and grid operators and planners are interested in how those resources perform and what modification needs to be considered to system resources and incentives for both grid reliability and resilience.
- **Performance profiles:** For example, while solar is typically coincident with peak load, high levels of penetration can create a spike in net load (demand less solar and wind output), increasing the need for always available resources to meet late afternoon load (see below). There is some complementarity between solar and wind, since onshore wind is most productive from evening until morning and during winter, when there are fewer daylight hours. But late afternoon/early evening power needs during summer may require conventional thermal generation to be available.
- **Smoothing variability:** Some of the variability in these resources can be smoothed through geographic dispersion (diversifying cloud and wind patterns). Further, there are a growing number of solar installations paired with storage systems to help balance these shortfalls, but so far they constitute a small percentage of projects.
- **Intermittency:** Solar and wind resources, while providing low-marginal cost energy, are by nature intermittent. Onshore wind typically operates at a 38% to 55% capacity factor, while large-scale solar PV can range from 21% to 34%. Performance also depends upon the type of system (e.g., tracking solar) and region.

Illustrative Solar and Wind Output and Net Load at Growing Penetration Levels in the Midwest



Source: MISO

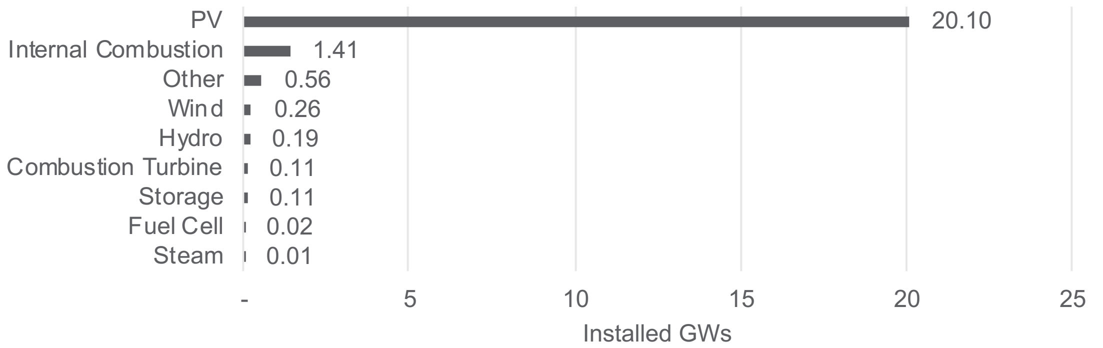
Sources: National Renewable Energy Laboratory, 2018 Wind Technologies Report (Aug. 2019); Lawrence Berkeley Nat'l Lab, Utility-Scale Solar: Empirical Trends in Project Technology, Cost, Performance, and PPA Pricing in the United States (Sept. 2018); Midcontinent ISO, Renewable Integration Impact Assessment, Presentation to Planning Advisory Committee (Apr. 18, 2018, updated June 18, 2018); Lazard, Lazard's Levelized Cost of Energy Analysis – Version 13.0 (Nov. 2019) (capacity factor assumptions).

Trend: DERs and Energy Storage

Growing DERs, Particularly Solar PV

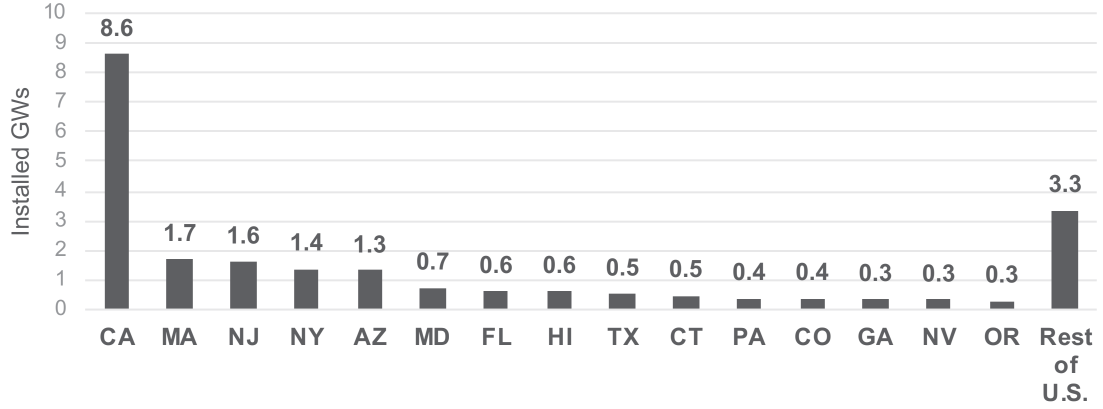
- **Declining installed costs:** As installed costs have declined, more distributed resources, particularly small-scale residential and commercial solar systems are being installed. Policies, such as net metering, mandates (such as California's mandate that new residential construction be equipped with rooftop solar), more aggressive RPS, and tax credits continue to encourage development of those systems. Development is also growing in areas with high-solar irradiance (e.g., Arizona, Florida, and Texas). However, distributed solar remains relatively costly compared with utility-scale resources, with unsubsidized levelized cost of energy (without subsidies) ranging from $73 to $267 per MWh, depending upon whether it is community solar, commercial, or residential installation.
- **Expected growth, albeit uneven:** DERs are expected to continue growing in selected regions. Wood Mackenzie projects growth ranging from 2% to 19% for residential rooftop solar systems because of resource fundamentals as well as policy developments. The federal investment tax credit step down for customer-owned systems in 2022 may briefly slow growth, but its effect is expected to be temporary.

Installed U.S. Distributed Generation by Type (2018) (GWs*)



Source: EIA

Installed U.S. Distributed Generation by State (GWs*) (Top 15 and Rest)



Source: EIA

Note: *Largely MW-ac, but includes some MW-dc.

Sources: Lazard, Lazard's Levelized Cost of Energy Analysis – Ver. 12.0 (Nov. 2018); SEIA/Wood Mackenzie Power & Renewables, Executive Summary (Public Version), U.S. Solar Market Insight Report 2019 Q3 (Sept. 2019), available at https://www.seia.org/research-resources/solar-market-insight-report-2019-q3; EIA Form ; EIA, Electric Power Monthly (Sept. 2019); ScottMadden analysis

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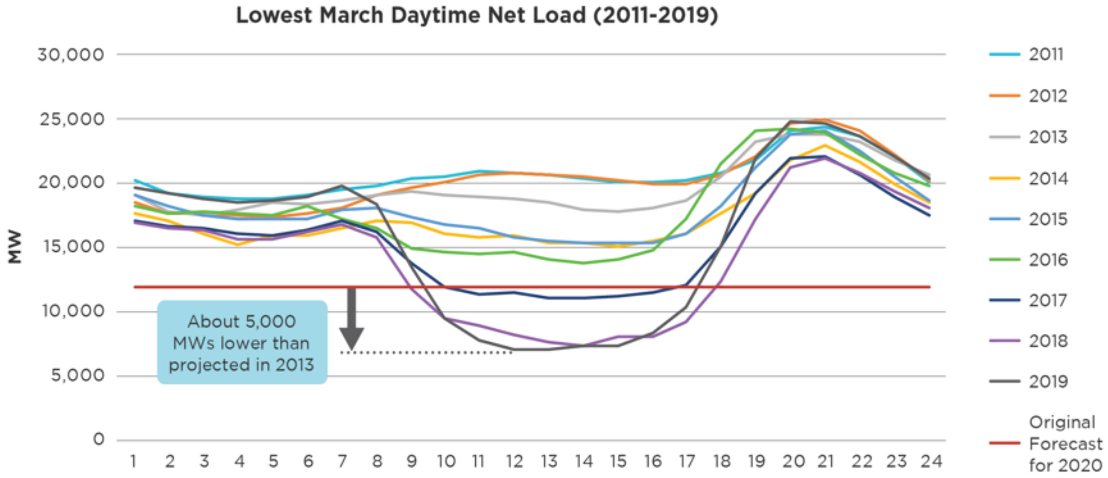
Trend: DERs and Energy Storage (Cont'd)

Growing DERs, Particularly Solar PV (Cont'd)

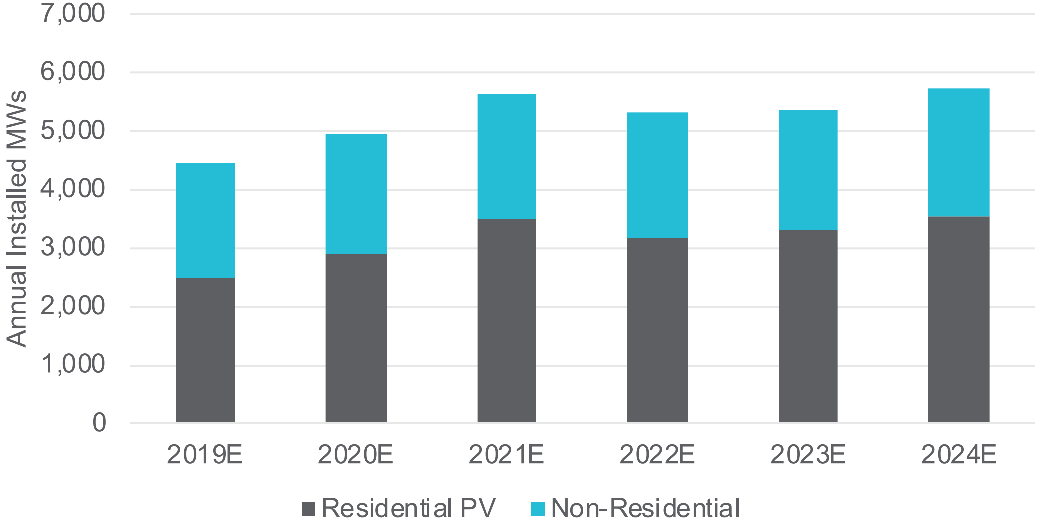
- **System impacts:** As DERs proliferate in some regions, large concentrations can affect the bulk power system in a number of ways. They can contribute to operational issues because of duck curve effects—lower net load conditions (load less solar and wind) followed by significant ramping needs in late afternoon during certain times of the year. In addition, DERs create variability in load (from self-supply) and potential backflows from the distribution system to the sub-transmission system, and they are not always visible to system operators. Transmission and distribution (T&D) system operators will have to manage increasing instances of control area energy imbalances and voltage fluctuations.
- **Megawatts in context:** With U.S. installed residential and commercial distributed solar totaling about 21 GWs, compared with installed utility-scale generation of nearly 1,100 GWs, DERs remain a small portion of total energy resources.

Duck Curve Effects from Utility-Scale Renewables and Lower Load (from Rooftop Solar Self-Supply)



Sources: CAISO; ScottMadden analysis

Projected U.S. Distributed Solar PV Installations by Year (Residential and Non-Residential) (MWs-dc)

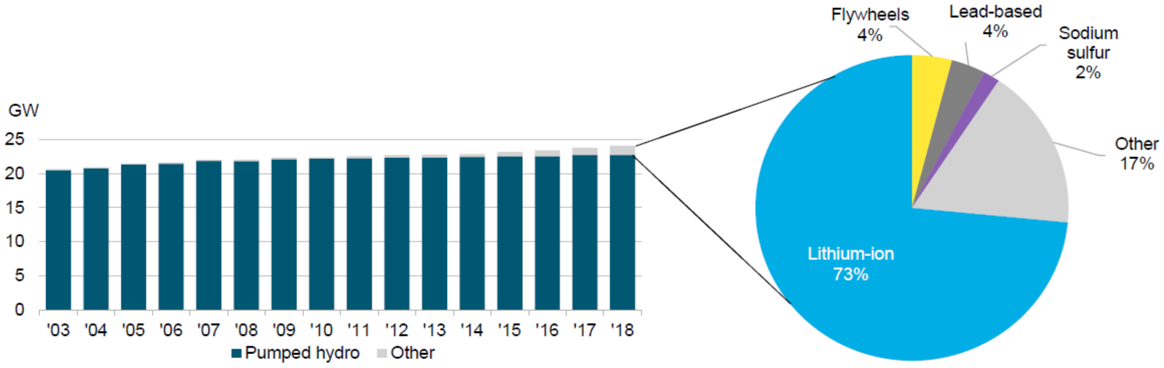


Source: SEIA/Wood Mackenzie

Sources: Lazard, Lazard's Levelized Cost of Energy Analysis – Ver. 12.0 (Nov. 2018); SEIA/Wood Mackenzie Power & Renewables, Executive Summary (Public Version), U.S. Solar Market Insight Report 2019 Q3 (Sept. 2019), available at https://www.seia.org/research-resources/solar-market-insight-report-2019-q3

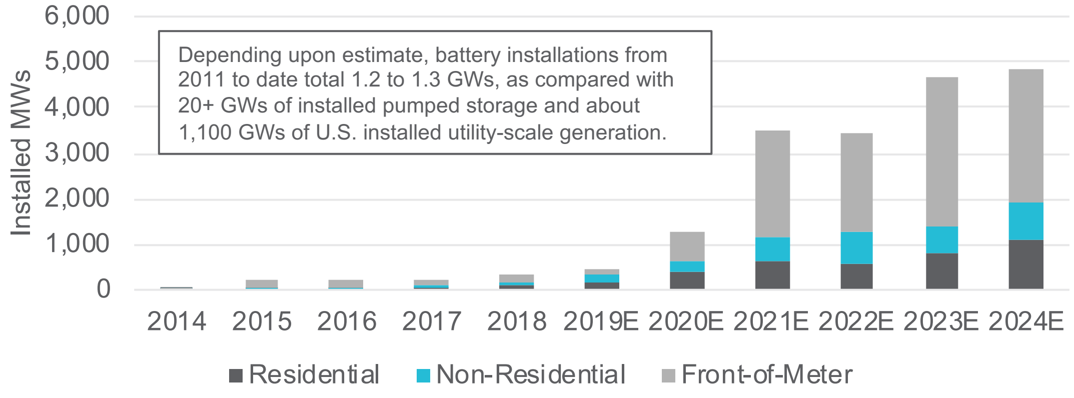
Trend: DERs and Energy Storage (Cont'd)

U.S. Storage Installations by Type



Source: BloombergNEF/BCSE

Actual and Projected Annual U.S. Battery Storage Installations by Year and Segment (MWs)



Source: Wood Mackenzie/Energy Storage Ass'n

Energy Storage Developments

- **Broad category:** Storage is a broad category of technologies that can store electric energy for later use. Pumped storage hydropower, a mature technology, accounts for 95% of installed storage capacity in the United States. Most new storage installations since 2011 have been lithium-ion (Li-ion) batteries. While typically not considered energy storage in policy discussions, reservoir hydropower has storage-like characteristics.
- **Drivers of storage:** Key drivers of energy storage include:
  - **Technology:** Advances in battery storage technology, in particular, battery chemistry, battery duration, and efficiency.
  - **Variable resource penetration:** Increasing penetration of renewable generation and DERs and the resultant need to integrate increasing numbers of variable resources into the grid.
  - **Declining cost:** Rapidly declining cost of energy storage systems, especially Li-ion driven by electric vehicle demand, is causing energy storage costs to fall sharply enhancing its cost competitiveness.
  - **State mandates and incentives:** For example, California (1,300 MWs by 2020), Massachusetts (200 MWhs by 2020), New York (3,000 MWs by 2030), and New Jersey (600 MWs by 2021; 2,000 MWs by 2030) have mandated storage procurement requirements.
  - **Federal policy:** FERC Order 841, issued in early 2018, is expected to encourage energy storage development. The rule mandates that organized power markets establish a participation model for electric storage resources, which consist of market rules that properly recognize the physical and operational characteristics of those resources.

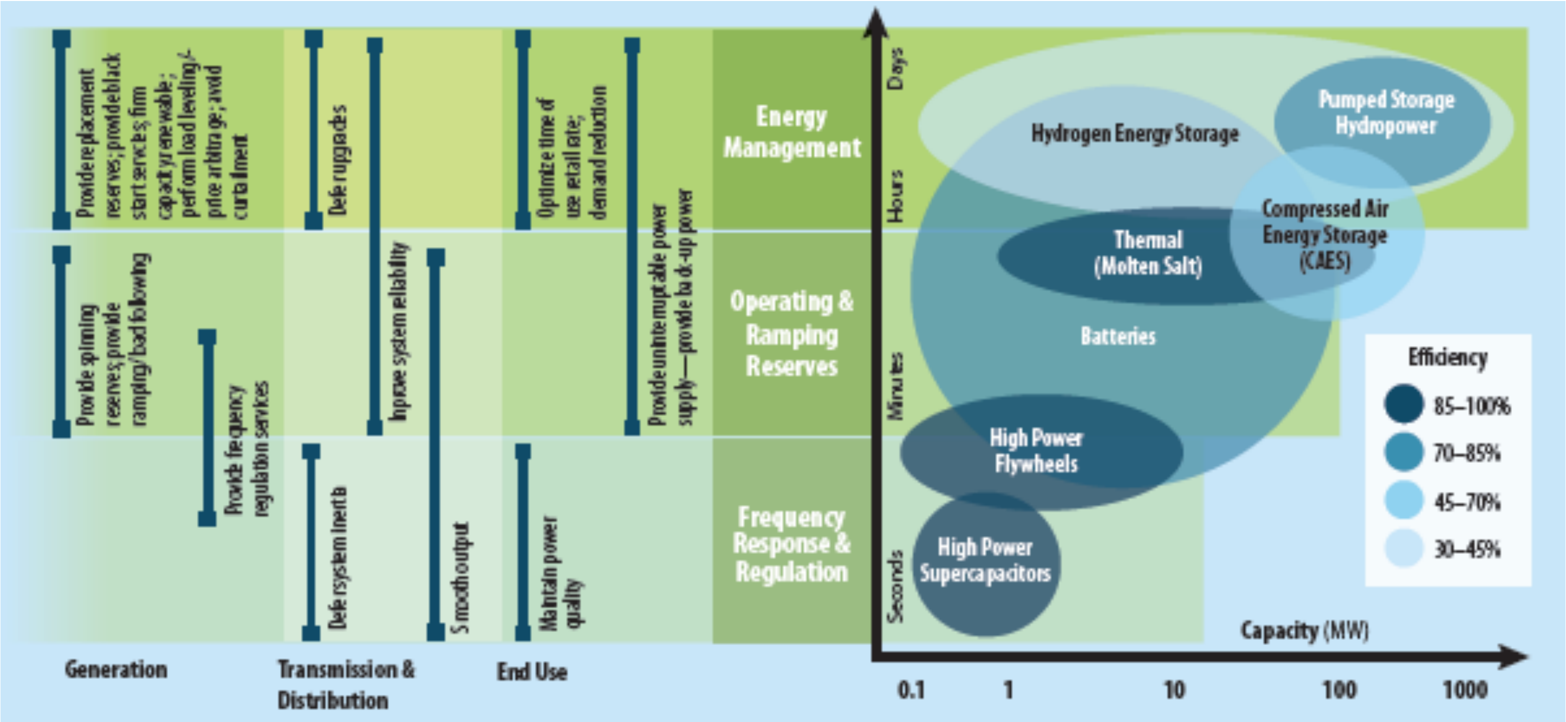
Sources: Wood Mackenzie Power & Renewables/Energy Storage Ass'n, Executive Summary (Public Version), U.S. Energy Storage Monitor Q3 2019 (Sept. 2019), available at https://www.woodmac.com/research/products/power-and-renewables/us-energy-storage-monitor; Bloomberg New Energy Finance/Business Council for Sustainable Energy, 2019 Sustainable Energy in America Factbook (Feb. 2019)

Trend: DERs and Energy Storage (Cont'd)

Energy Storage Developments (Cont'd)

- **Multiple services:** Energy storage can perform a variety of applications across the power system, whether as a customer resource, a grid resource, or as a bulk electric system resource, both behind- and front-of-the-meter. Depending upon its size and discharge duration, storage can be treated as a distributed resource or a bulk power (wholesale) resource. This enhances the value of storage, as it can perform multiple roles (e.g., peak reduction, ancillary services, capacity or T&D upgrade deferral) (see graphic below).

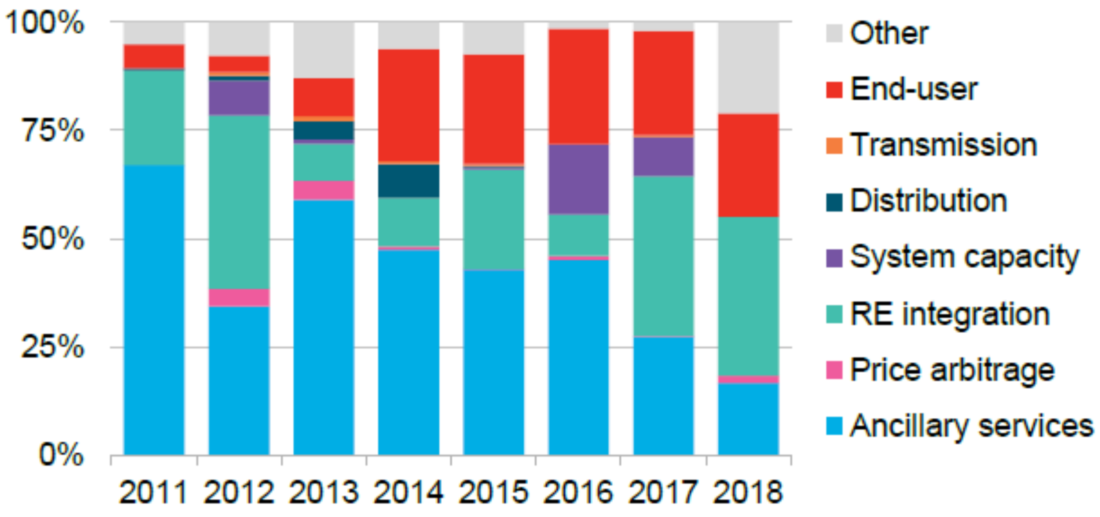
Storage Technology Characteristics and Potential Grid Applications



Sources: Bloomberg New Energy Finance/Business Council for Sustainable Energy, 2019 Sustainable Energy in America Factbook (Feb. 2019); NREL, Energy Storage: Possibilities for Expanding Electric Grid Flexibility (Feb. 2016); AWEA, Grid Vision: The Electric Highway to a 21st Century Economy (May 2019)

Trend: DERs and Energy Storage (Cont’d)

U.S. Storage Applications (% of MWs)



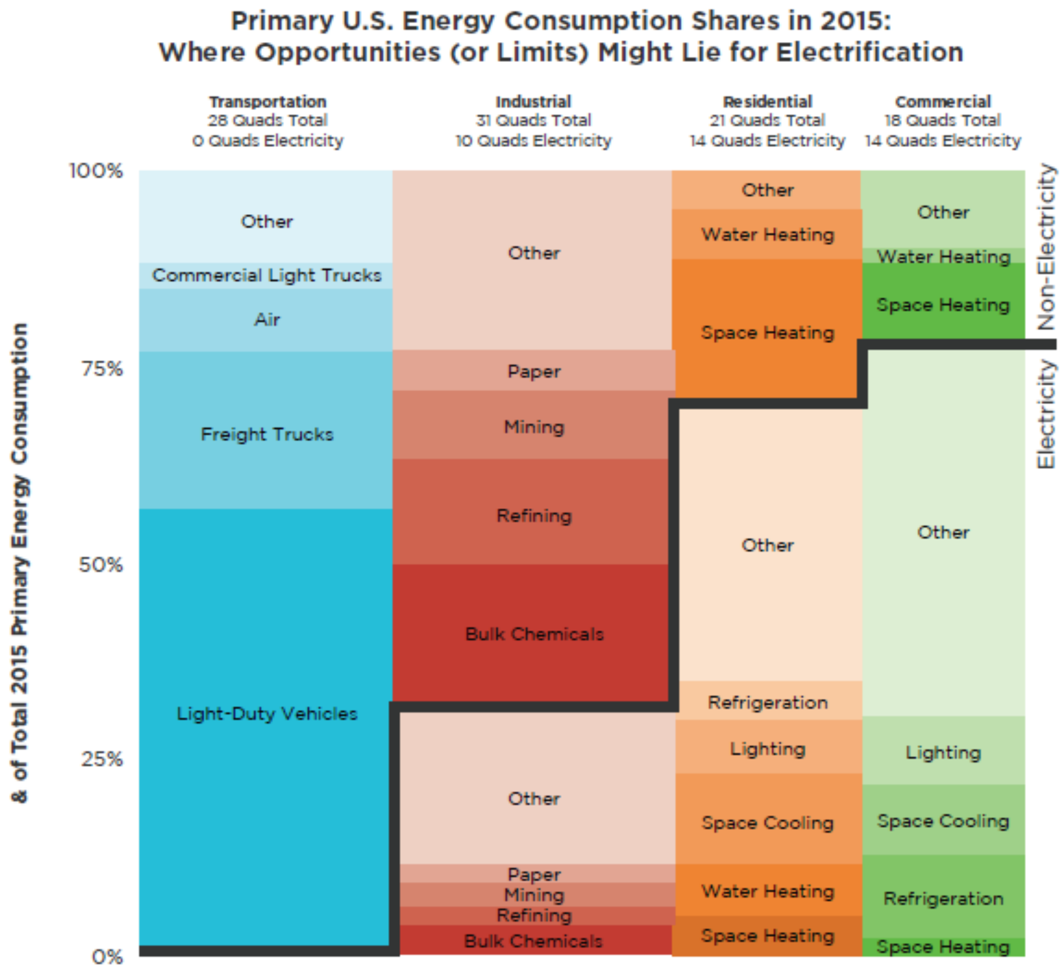
Energy Storage Developments (Cont’d)

- **Grid ally, with limits:** Storage can help provide frequency and voltage support from grid perturbations as well as from variability from renewable resources. It can also serve as a sink for excess variable resource output and support output for evening ramps. A growing amount of solar plus battery storage installations reflects this grid support function. This can also support microgrid and other grid isolation applications to increase resilience in the event of short-term events. But while batteries provide good short-term (up to four hours duration) output, they are not currently well-equipped to provide longer-term duration (i.e., eight hours plus) of output and which, at current cost and scaled to gigawatts, could be prohibitively expensive. Some observers contend that high penetrations of wind and solar resources in a low-carbon grid will require energy storage of greater duration than hours, perhaps monthly or seasonal.
- **While storage holds promise to add value across various parts of the power system, the benefits are typically focused locally. Pumped storage hydro, the largest installed storage resource, is dependent upon geography and geology, making it location-specific and dependent upon transmission. For large-scale, long-distance, high-efficiency movement of energy, current and foreseeable energy storage technology can complement, but not replace, power transmission’s capabilities.**

Sources: Bloomberg New Energy Finance/Business Council for Sustainable Energy, 2019 Sustainable Energy in America Factbook (Feb. 2019); NREL, Energy Storage: Possibilities for Expanding Electric Grid Flexibility (Feb. 2016); AWEA, Grid Vision: The Electric Highway to a 21st Century Economy (May 2019)

Trend: Electrification

- **After flat load growth, electrification potential:** A combination of efficiency and structural changes in the economy (less energy intensity) has reduced electricity demand. However, environmental and climate change advocates, as well as some electric utilities, see environmental benefits from increased electrification (termed beneficial or efficient electrification), with a less carbon-intensive generation mix, as a key component for cost-effective reduction in global emissions.
- **Transportation is key:** Transportation is now the largest source of U.S. carbon emissions, and it has the highest and most immediate potential for electrification (especially light-duty vehicles), while electricity could continue to displace natural gas in the buildings sector, particularly for space and water heating.
- **Growth potential of about 1% per year:** In a national electrification assessment, the Electric Power Research Institute (EPRI) examined scenarios for increased electric use in current non-electric applications. It estimated 32% electricity growth between 2015 and 2050 (0.8%/year), and a higher 1.2%/year growth for a more aggressive electrification scenario (with a significant carbon price). The National Renewable Energy Laboratory (NREL) performed a similar analysis, finding increased use and a potentially higher load factor (see charts on next page).



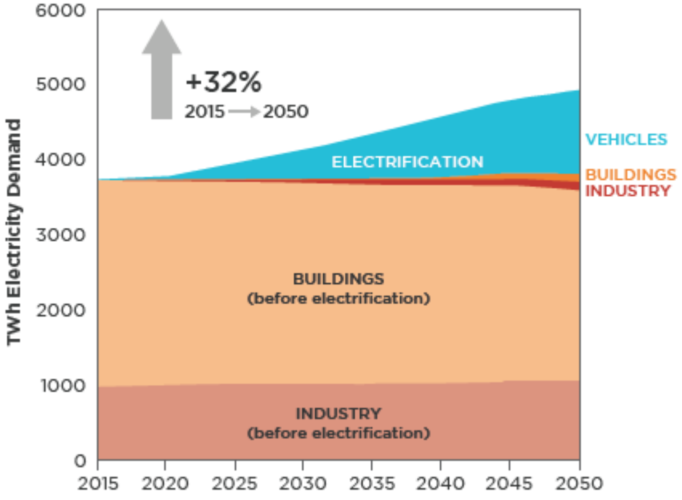
Source: NREL

Sources: Electric Power Research Institute, U.S. National Electrification Assessment (April 2018); National Renewable Energy Laboratory, Electrification Futures Study: Scenarios of Electric Technology Adoption and Power Consumption for the United States (July 2018); WIRES/The Brattle Group, The Coming Electrification of the North American Economy (Mar. 2019)

Trend: Electrification (Cont'd)

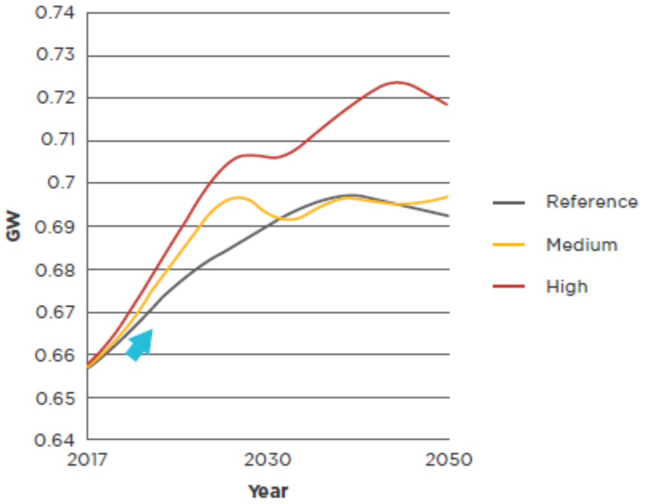
- **Cost challenges and key assumptions:** High upfront costs, low natural gas prices, incumbency technology advantages, and technological challenges may prevent the widespread electrification of some applications. For example, location matters for some "electrified" applications, such as heat pumps, which have historically not performed as well in very cold climates (although there have been some efficiency improvements) and often require a supplemental heat source. To achieve EPRI's scenarios, the share of electrification of transportation and building space-heating by 2050 is significant (40% and 50%, respectively). The required investment and policy incentives to achieve these levels of penetration are as yet undetermined.
- **Uncertainty and transmission impacts:** As noted by The Brattle Group, increased vehicle electrification could require reconfiguration or at least increased transmission capacity that would supply fast-charger facilities along highway corridors and in urban areas. Increased electrification of space-heating may increase winter-peak loads, a phenomenon being observed in the Southeast. To achieve emissions reductions, cost-effective renewable generation will likely have to be connected to load to meet at least a portion of incremental electrification demand.

EPRI Reference Electrification Scenario: Electricity Demand (TWh) by Sector



Source: EPRI

Load Factor Estimates for NREL Electrification Scenarios (Current and in 2050)

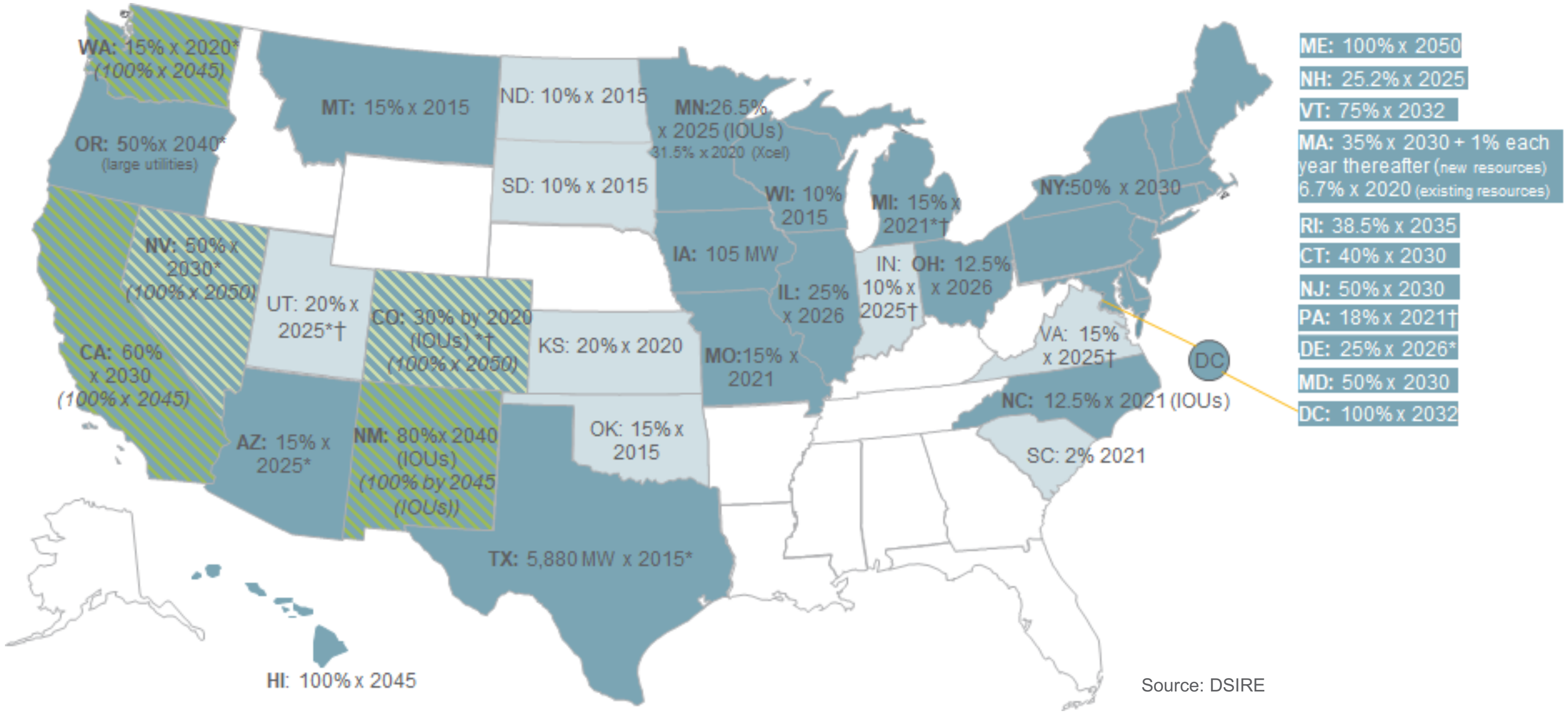


Source: NREL

Sources: Electric Power Research Institute, U.S. National Electrification Assessment (April 2018); National Renewable Energy Laboratory, Electrification Futures Study: Scenarios of Electric Technology Adoption and Power Consumption for the United States (July 2018); WIRES/The Brattle Group, The Coming Electrification of the North American Economy (Mar. 2019); American Gas Association, Implications of Policy-Driven Residential Electrification (July 2018)

Trend: Increasing Clean Energy Goals and Preferences

State Renewable and Clean Energy Goals (as of June 2019)



Renewable portfolio standard	*Clean energy standard*	* Extra credit for solar or customer-sited renewables
Renewable portfolio goal	*Clean energy goal*	† Includes non-renewable alternative resources

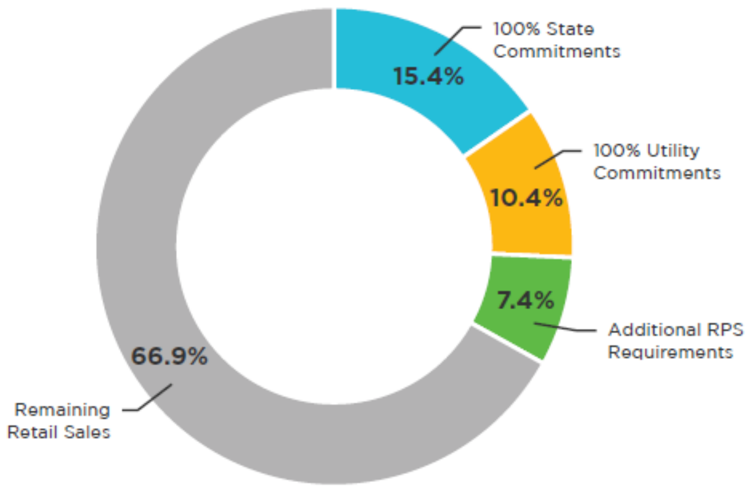
- **States ratchet up goals and standards:** Driven by citizen interest and customer preferences, states are increasing their renewable targets and/or establishing clean energy standards. Those targets are typically tied to retail sales, although some states express them as a percentage of generation. Twenty-nine states plus the District of Columbia have RPS, while three have clean energy standards.
- **Different approaches:** Clean energy standards are typically one of three types: (1) carbon-neutral (net-zero carbon), which doesn't require full decarbonization of the sector but allows for carbon-offsetting or capturing applications; (2) carbon-free, which can include both renewable and non-carbon-emitting technologies like nuclear power; and (3) renewables-only, which typically target a percentage of generation or load to be served with non-hydro renewables.
- **Longer-term goals:** Some states have set long-term aspirations for 100% clean or carbon-free energy by dates ranging from 2040 to 2050.
- **Declarations-only for some states:** A few states (e.g., Virginia and Colorado) have had pronouncements by their respective governors setting targets and charging regulators with advancing them, but the goals have not been codified in legislation.

Sources: S&P Global Market Intelligence, "US states face uneven paths in movement for 100% 'clean energy'" (Aug. 21, 2019); S&P Global Market Intelligence, "Renewables, distributed energy make a splash at regulators' summer meetings" (Aug. 5, 2019); Database of State Incentives for Renewables & Efficiency (DSIRE)

Trend: Increasing Clean Energy Goals and Preferences (Cont'd)

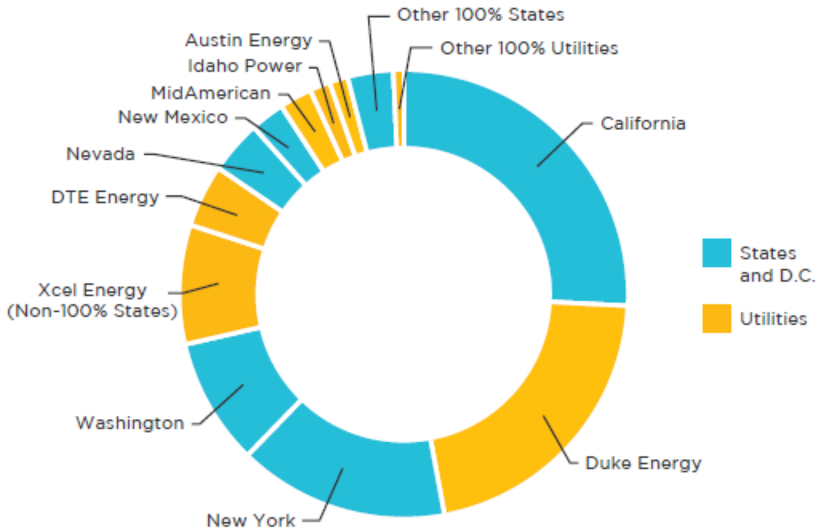
- **Utilities moving even without state action:** Some utilities have committed to clean energy goals, even in the absence of state mandates. Xcel Energy, Duke Energy, and DTE Energy are the largest utilities (in retail sales) to date that have committed to 100% clean energy or net-zero carbon emission by 2050, and others have made similar commitments (see charts below).
- **Corporate buyers remain active:** Even as states and utilities increase commitments to renewable and clean energy, large corporate purchasers are establishing targets for purchase of renewable energy. According to Bloomberg New Energy Finance (NEF), through 2018, 158 companies have pledged to source 100% of their energy consumption from renewables by signing onto the "RE100" initiative; 32% of these firms are domiciled in the United States. Further, renewable power purchase agreements between generators and corporate purchasers surged to 8.6 GWs in 2018; 2.5 GWs of that amount were contracted by Facebook (see next page).

100% Clean Energy Commitments and RPS Requirements (as Percentage of 2018 Retail Electricity Sales)



Sources: Industry news; EIA data; ScottMadden analysis

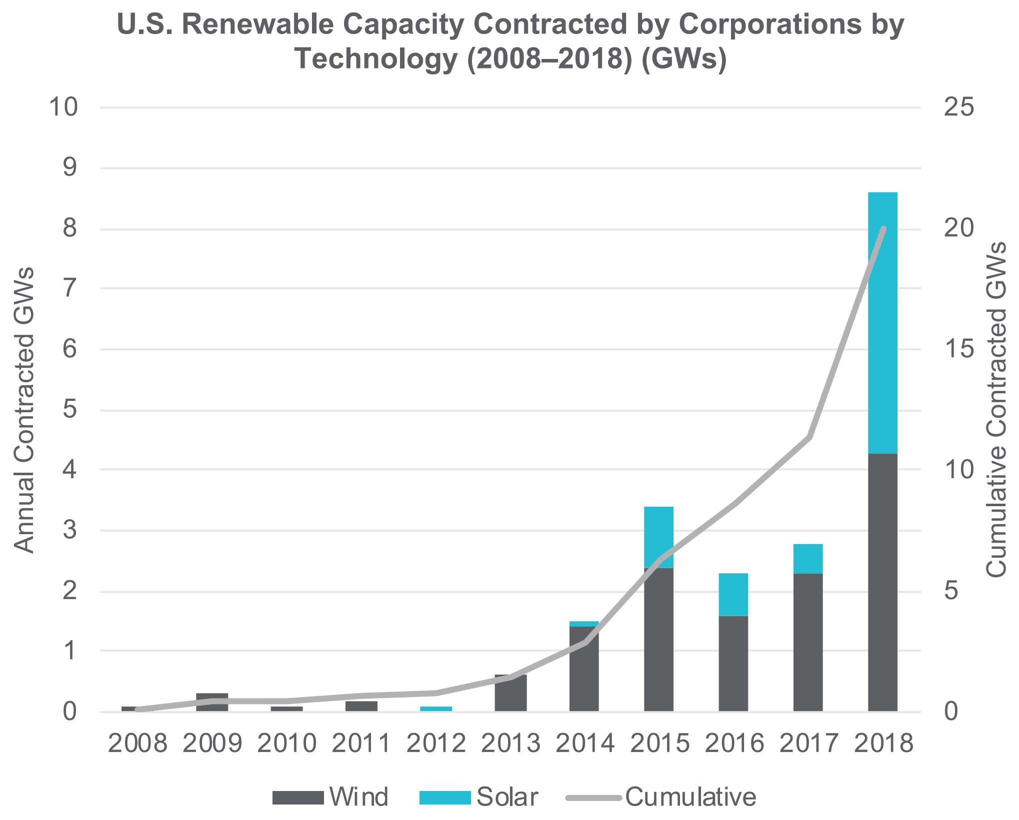
100% Clean Energy Commitments by State and Utility (Based on 2018 Retail Electricity Sales)



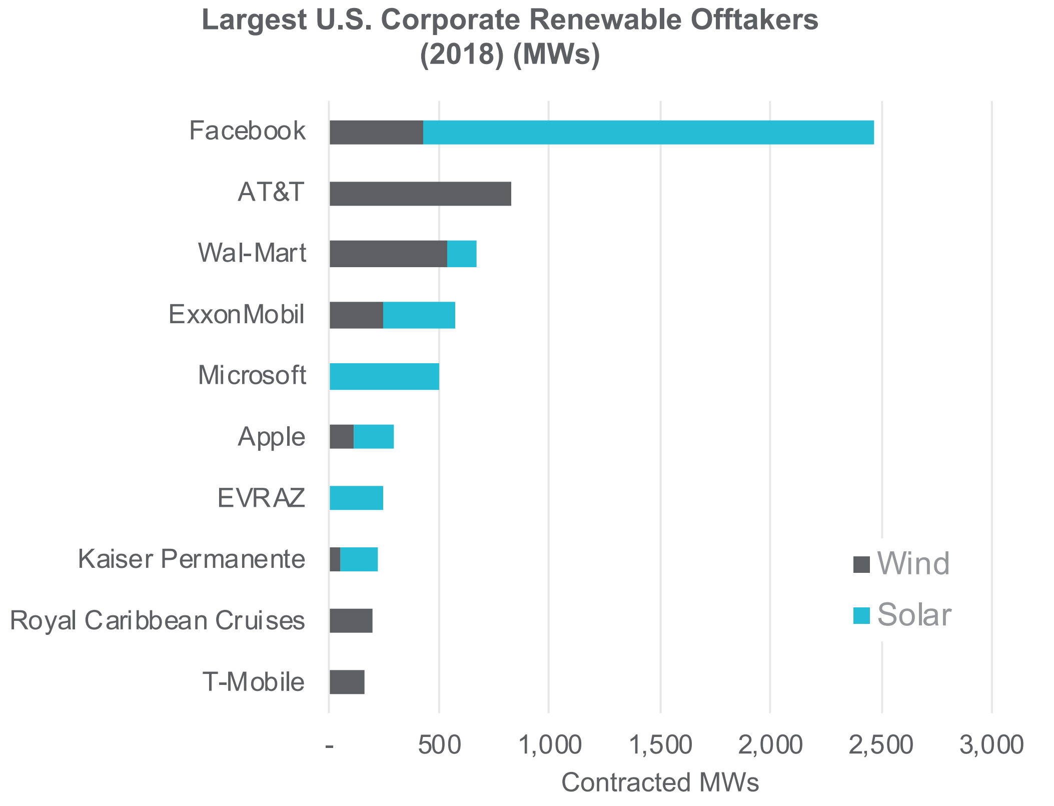
Note: Only the state commitment is counted if both the state and an electric utility have 100% clean energy commitments.
Sources: Industry news; EIA data; ScottMadden analysis

Sources: Bloomberg New Energy Finance/Business Council for Sustainable Energy, 2019 Sustainable Energy in America Factbook (Feb. 2019); industry news; EIA data; ScottMadden analysis

Trend: Increasing Clean Energy Goals and Preferences (Cont'd)



Source: BloombergNEF



Source: BloombergNEF

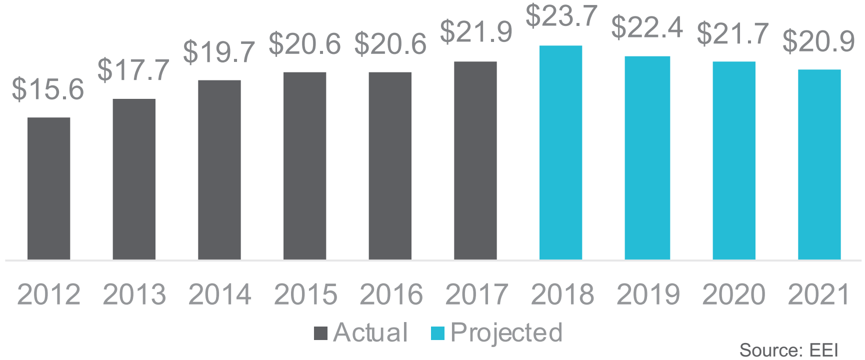
- With the anticipated demand for renewable and non-emitting generation created by these standards and goals, there is widespread expectation of continued renewable generation development and the capability to deliver clean power to jurisdictions that mandate it.

Sources: Bloomberg New Energy Finance/Business Council for Sustainable Energy, 2019 Sustainable Energy in America Factbook (Feb. 2019); industry news; EIA data; ScottMadden analysis

Considering Transmission – Why It Matters

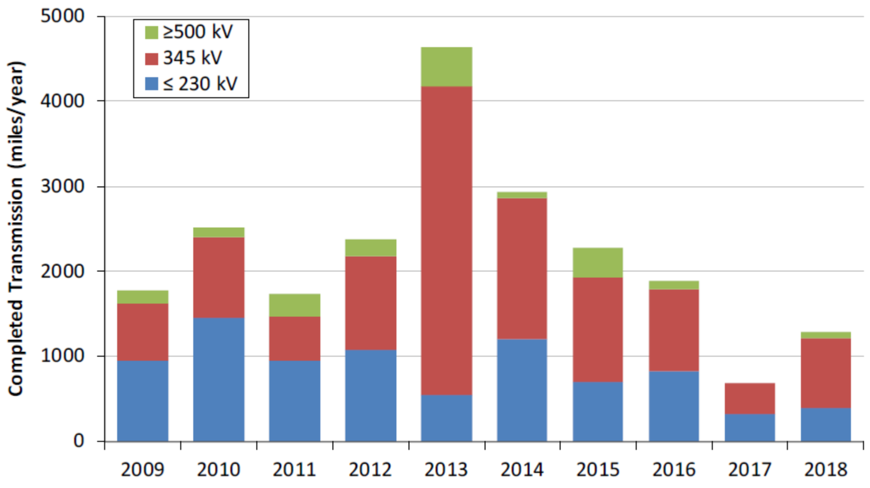
- Transmission investment has continued apace in recent years (see top right). However, only about 1,300 miles of transmission was completed in 2018 versus a recent peak in 2013 (see bottom right). That peak was largely due to the completion of Texas' Competitive Renewable Energy Zones, which established a "build it and they will come" approach to transmission development to accommodate renewable integration.
- Based upon the foregoing, there are some significant potential impacts of these trends on our nation's transmission system, which warrant revisiting the need for transmission investment. Those impacts are described further below:
  - **Transmission expansion and changing energy mix:** With the anticipated growth in renewable resources, power flows will be more intermittent and time-varying. While gas-fired capacity and storage can help mitigate some variability, transmission can provide flexibility to balance the system with diverse resources, provide long-distance, efficient backbone to move renewable resources, and provide congestion relief to better utilize zero-marginal cost resources.
  - **DERs and energy storage introduce benefits and some complexity:** The introduction of DERs can provide the ability to serve, or reduce, load in a dispersed manner. This can provide some resilience benefits during extreme weather events when distribution facilities are temporarily compromised.
    - **Demand-side variability:** However, these resources introduce demand-side variability and can tax the transmission system with potential backflow issues. Massachusetts is already examining these issues, requiring transmission planners to look at system impacts and the potential need for upgrades.

Historical & Projected Transmission Investment* ($ Billions) (as of Oct. 2018)



Source: EEI

Miles of Transmission Projects Completed by Year and Voltage



Source: DOE; FERC

Note: *By investor-owned electric companies and stand-alone transmission companies
Sources: DOE; FERC; Edison Electric Institute (EEI), at www.eei.org/issuesandpolicy/transmission/Pages/default.aspx

Considering Transmission – Why It Matters (Cont'd)

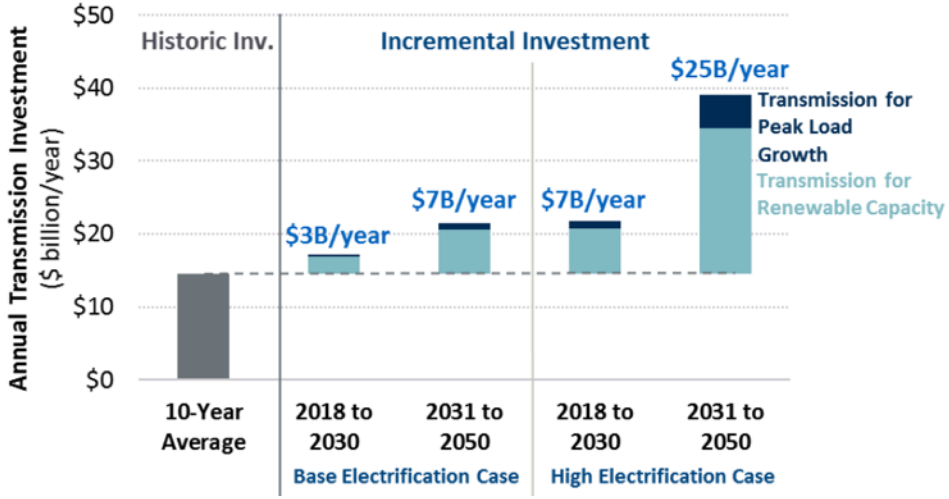
- **DERs and energy storage introduce benefits and some complexity (cont'd)**
  - **Storage pros and cons:** Energy storage can be a partner with transmission in supporting the grid with ramping capability, ancillary services, and absorbing excess low or negative cost energy during off-peak hours. In some regions, these facilities are being teamed with variable resources (both solar and wind) to provide some temporal smoothing of energy output as intra-day solar generation increases and declines and to moderate temporary reductions in wind output when wind abates. But even the best battery storage is limited in duration, from four hours to eight hours, and longer durations will require a significant scaling of storage capacity. And scaling that capacity will require a level of investment that is not yet contemplated in development forecasts.
  - **Reservoir hydropower:** As mentioned earlier, reservoir hydropower has storage-like characteristics and is abundant in Canada, adjacent to U.S. markets. Canada has 81 GWs of installed hydro (including pumped storage) (over 40 GWs in Quebec alone) and the technical potential for development of an additional 155 GWs.
  - **Transmission's role:** Transmission capacity can provide flexibility to move, at an aggregated level, avoided energy and to optimize cost of energy for all customers, providing option value in moving resources where needed factoring in congestion, grid needs, economics, and customer preferences. It can also provide broader market access for storage resources, including reservoir hydropower as noted above. In addition, investment in increased visibility into DERs and flexibility and control systems to accommodate non-traditional, more granular resources, such as storage, may be needed as these resources continue to come online. However, a one-size-fits-all approach will be ill-suited to considering transmission, as policies and resource potential (e.g., solar irradiance) varies among regions and states.
- **Electrification-driven demand may change locational needs of grid:** It is unclear whether efforts to electrify the grid will result in substantial growth in demand. But the potential for conversion of primarily transportation and building electrification and the possible impacts on demand—and hence incremental deliverability of new resources—must be considered, given the roughly 10 or more years timeline for development of U.S. transmission projects.
  - **Impacts of electrification:** A recent study by The Brattle Group and WIRES noted that electrification may have two impacts: higher secular demand for electricity and increased need to access renewable energy supply—wherever it has the greatest technical and economic potential—to provide marginal energy resources that have the "beneficial" clean characteristics either demanded by customers or reducing "social costs" in the form of lower emissions.
  - **Vehicle electrification as key driver:** Studies of electrification potential, notably including EPRI's latest national electrification assessment, project the greatest impact on demand from electrification as deriving from transportation electrification. Why does this matter? Widespread vehicle electrification is forecast to require significant build-out of charging infrastructure, both in municipalities as well as along major highways and thoroughfares. The WIRES/Brattle report noted above pointed to the potential need for DC fast-charging infrastructure in urban environments as well as along highways, which could drive demand for transmission assets in new locations.

Sources: WaterPower Canada, at https://waterpowercanada.ca/learn/; Hydro-Quebec, Decarbonizing the Northeast (Jul. 26, 2018); WIRES/The Brattle Group, The Coming Electrification of the North American Economy (Mar. 2019)

Considering Transmission – Why It Matters (Cont'd)

- **Electrification-driven demand may change locational needs of grid (cont'd)**
  - **Transmission potential:** EPRI estimates that electrification could drive 1%+ annual growth in electric demand growth. Brattle estimates a potential for near-term (through 2030) demand growth of 5% to 15% per year and a potential need for $30 to $90 billion in incremental transmission investment over the same period. That investment is principally to connect renewable resources to serve total energy demand and to ensure system reliability with increasing peak demands (see graph at right). Without ascertaining specific needs, beneficial electrification will entail linking renewable supplies with changing demand locations (e.g., highways) and patterns.
- **Clean energy targets will drive the continued need to bring non-emitting resources to market:** Over the intermediate to long term, demand for renewable resources to meet ambitious clean energy and net-zero carbon emissions targets will encourage continued development of renewables, but particularly utility-scale wind and solar resources.
  - But this development is taking place in patchwork form, differing by region and even adjacent states. For some states, the pace of development may be at a speed not heretofore contemplated.
  - Transmission investment will be required to help states and utilities with clean power targets meet their energy needs with the most cost-effective and abundant resources. The United Nations Intergovernmental Panel on Climate Change (IPCC) recently acknowledged that significant electricity transmission investment will be needed globally as part of a mitigation pathway targeting a limit of global warming of 1.5°C above pre-industrial levels.
  - Frictions may occur, however, as the lack of policy alignment among states sharing a market area or region can create conflict over who should pay for transmission investment, despite potential overall market benefits including added resilience.

Annual Incremental Transmission Investment Due to Electrification*



Source: The Brattle Group/WIRES

Note: *The historical average reflects transmission investments from 2006 to 2016 based on transmission capital expenditures reported on FERC Form 1.

Sources: The Brattle Group/WIRES, The Coming Electrification of the North American Economy (Mar. 2019); U.N. IPCC, Global Warming of 1.5°C: An IPCC Special Report (2018)

Considering Transmission – Why It Matters (Cont'd)

Key Points

- Clean energy goals are getting more common and ambitious, with potential transmission investment needs for the integration of new renewable resources.
- With the growth in decentralization of resources, visibility and control at the transmission level will be critical and investment in technology to facilitating grid reliability and efficiency.
- A key unknown is the potential for load growth through beneficial electrification. With significant electric vehicle adoption, space-heating conversion, and other potential electrification pathways, grid investment (including transmission) will be needed to accommodate new demand characteristics.
- However, renewable integration and resilience issues can be regional in nature, as each has its own blend of existing generation and transmission assets, load profiles, renewable resource potential, electrification potential, and risks from widespread resilience events. Due deference should be given to those regional differences, but broader interregional and societal goals should be considered as well.