Wind energy helps build a more reliable and balanced electricity portfolio

American Wind Energy Association I www.awea.org

AMERICAN WIND ENERGY ASSOCIATION

Executive Summary

Some of the most common questions about wind energy focus on how wind can be reliably integrated into the power system. A key source of confusion is that, contrary to most people's intuitive experience that winds are variable and electricity demand and supply is stable, the opposite is actually true at the grid operator scale. The following report answers 15 of the most frequently asked questions with lessons learned from grid operators' experiences reliably integrating large amounts of wind. Concise answers to these questions are provided here in the executive summary, while citations and explanations of the supporting data and analysis for those answers can be found by following the hyperlinks to the relevant sections of the full report below.

1. How much wind energy is on the power system now?

U.S. wind energy provides enough electricity to power the equivalent of over 18 million homes. Iowa and South Dakota reliably produced more than 25% of their electricity from wind last year, with a total of nine states above 12% and 17 states at more than 5%. At times, wind has supplied more than 60% of the electricity on the main utility system in Colorado, and nearly 40% of the main Texas power system.

2. How do grid operators accommodate such large amounts of wind energy?

Variability and uncertainty are nothing new for grid operators, as they have always dealt with large and unexpected fluctuations in electricity supply and demand by changing the output of power plants. Most changes in wind output are canceled out by other offsetting changes in electricity supply and demand, and any remaining variability is accommodated using the same flexible reserves that grid operators have always used. In fact, because changes in wind output occur gradually and can be forecast, they are less costly for grid operators to accommodate than the abrupt failures of large conventional power plants.

3. How much does it cost to integrate wind?

Grid operator data show that the cost of the incremental flexible reserves needed to accommodate wind amount to pennies on a typical electric bill. In fact, the cost of accommodating the unexpected failures of large conventional power plants is far higher.

4. How much more wind energy can we reliably integrate?

While U.S. and European grid operators have already reliably integrated large amounts of wind energy, studies indicate that we can go far higher. Studies examining obtaining 40% or more of our electricity from wind have found no major obstacles to doing so. Ten years ago some utilities and grid operators were concerned about reaching 5% wind; they now have a lot more experience to draw from, and over the next ten years, they will surely learn more and be able to continue increasing reliable penetration.

5. Don't grid operators need to add backup to integrate wind?

No. One of main reasons why an integrated power system was first built more than 100 years ago was so that all power plants could back up all other power plants. Because most sources of variability cancel each other out, having a dedicated backup source for each would be highly inefficient and counterproductive.

6. What happens when the wind doesn't blow?

Other plants provide energy at those times, in the same way that all power plants back up all other power plants. Portfolio diversity is the key, as no resource is available 100% of the time. All power plants have reduced output at times, and grid operators plan for wind's contribution using the same tools they use to evaluate the contributions of other resources. Adding wind power never increases the need for power plants, but rather reduces it. During a number of events wind has demonstrated its contribution to a more reliable and diverse energy portfolio by stepping in when other resources failed unexpectedly.

7. Don't we need baseload power?

Instead of using the term "baseload," it is more productive to talk about the three main services the grid needs to operate reliably: energy, capacity, and flexibility. Energy is the production of electricity, capacity is the ability to produce power during periods of high demand, and flexibility is the ability to change output to keep supply and demand in balance. Cost-effectively obtaining all three services requires a division of labor among a diverse mix of energy sources, as no resource excels at providing all three. For example, baseload resources typically do not provide flexibility, and there can be lower-cost ways of obtaining the energy and capacity provided by baseload. Wind energy primarily adds value to an energy portfolio as a low-cost and non-polluting source of energy, though it also provides some capacity and can provide flexibility when it is economic to do so.

8. What about the reliability services provided by conventional generation?

As wind energy has grown to provide a larger share of our electricity mix, wind turbine technology has matured so that modern wind plants are able to provide the same grid reliability services as conventional generators, including voltage and reactive power control, frequency and inertial response, active power control, and voltage and frequency ride-through. In some cases the reliability services provided by wind exceed those of conventional generators, while in other cases conventional generators can provide those services more economically than wind generators, but wind generators can provide those services if it becomes economic to do so.

9. What has been Europe's experience with renewable energy?

European nations have demonstrated that wind energy can reliably provide a large share of our electricity, with Ireland, Spain, and Portugal obtaining around 20% of their electricity from wind on an annual basis, Germany at 25% from wind and solar, and Denmark at nearly 35% wind. Carbon emissions have fallen drastically in all of these countries, while electric reliability has been maintained at world-leading levels and in many cases improved.

10. What is needed to reliably accommodate higher levels of wind?

Market-based grid operating reforms and transmission upgrades are by far the lowest hanging fruit for making the power system more efficient by using more of the flexibility that already exists on the power system. These grid operating reforms provide major net benefits to consumers and improve reliability even without renewable energy on the power system, so they should be pursued regardless.

11. Isn't energy storage necessary to integrate wind?

No. Very large amounts of wind energy can be reliably integrated at low cost without a need for energy storage. Energy storage provides a variety of services and is therefore best viewed as a power system resource and not a resource for renewable energy. Energy storage is typically a more expensive source of flexibility than grid operating reforms that allow greater use of the flexibility that already exists on the power system.

12. Why is some wind power curtailed? How does time of production affect the value of wind energy?

In some areas the growth of wind energy has outpaced the addition of transmission. At times this has required reducing, or curtailing, the output of wind plants until new transmission is added. However, as long-needed grid upgrades are completed, wind curtailment is being virtually eliminated, as are occurrences of negative electricity prices. Wind energy always has high economic value, particularly once the environmental and public health costs of fossil fuel generation are taken into account.

13. How does the renewable energy Production Tax Credit affect electricity markets and reliability?

Wind and the production tax credit are compatible with well-functioning electricity markets. Wind's impact on other generators is market-driven and the same as that of any low-cost generator, and trivially small compared to other factors.

14. What is wind's net impact on emissions?

Wind energy greatly reduces emissions of carbon dioxide and other pollutants after all impacts on other power plants are taken into account.

15. Can wind reliably reach the level of output EPA assumed in its Clean Power Plan?

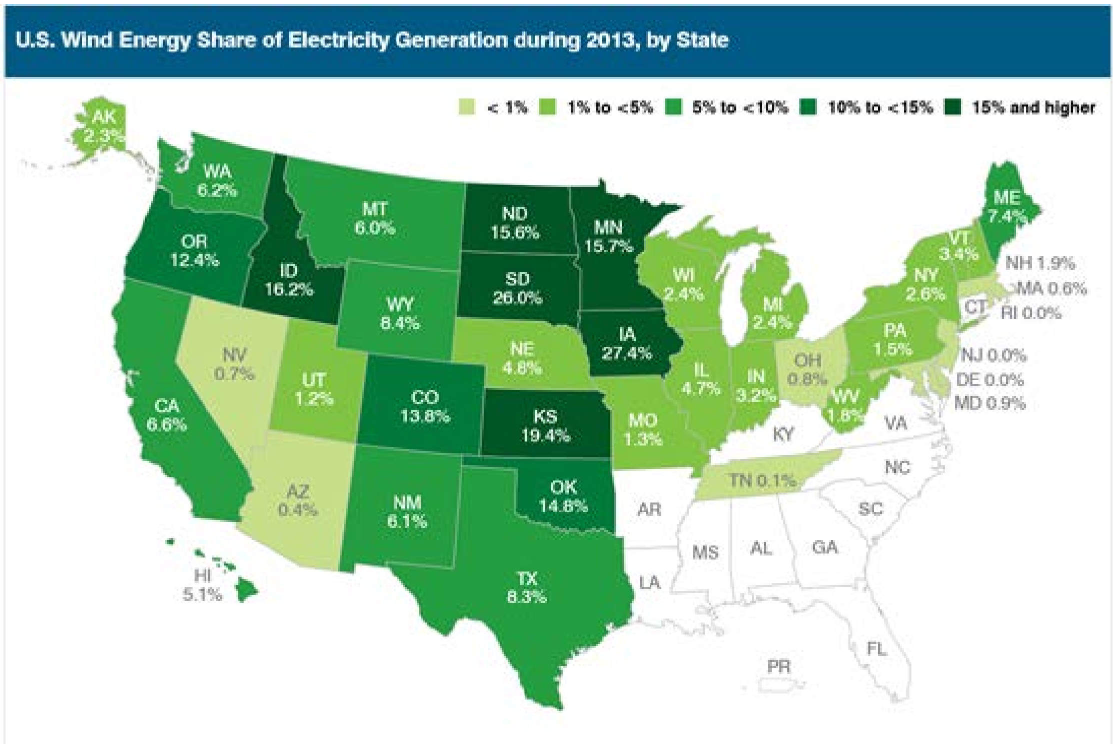
Yes. Renewable energy has already met EPA's 2020 target and is well on its way to greatly exceed EPA's 2020-2030 targets. By exceeding its targets, wind energy can help comply with other parts of EPA's plan, lessening the requirements on other parts of the electric sector.

As should be apparent from the extensive evidence provided in the full text below, this report seeks to distill tens of thousands of pages of analysis by grid operators and other experts into a more digestible document. Additional technical support for the points made in this document can be found in a similar 2009 FAQ authored by some of the world's leading wind integration experts.[1]

[1] http://www.ieee-pes.org/images/pdf/open-access-milligan.pdf

1. How much wind energy is on the power system now?

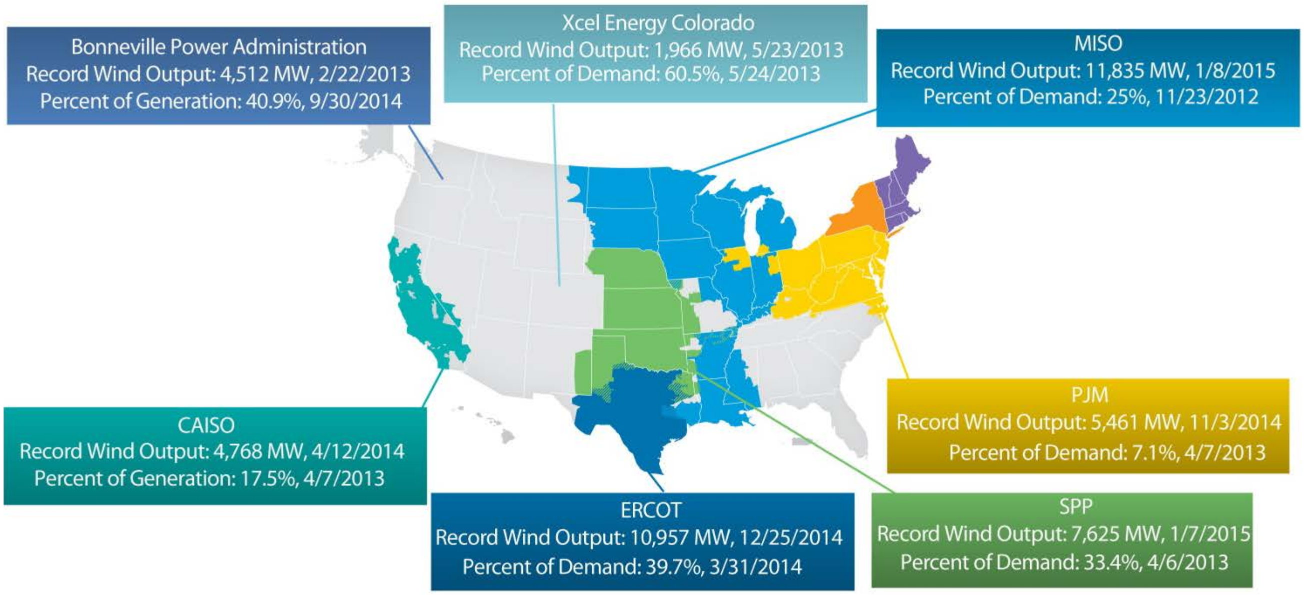
U.S. wind energy provides enough electricity to power the equivalent of over 18 million homes. Iowa and South Dakota produced more than 25% of their electricity from wind in 2013, with a total of nine states above 12% and 17 states at more than 5%. Wind energy provided 10.6% of the electricity last year on the main power system in Texas,[2] ERCOT, and that figure is expected to reach 15-20% by 2017.[3]



At certain times, wind output levels have gone even higher. The graphic below shows wind generation records and the record percent of demand or generation from wind. At times, wind has supplied more than 60% of the electricity on the main utility system in Colorado, nearly 40% of the main Texas power system, and 33% in the Southwest Power Pool, all without any reliability problems.

[2] http://ercot.com/news/press_releases/show/51654
[3] http://www.ercot.com/content/committees/board/keydocs/2014/ERCOT_Monthly_Operational_Overview_201412.pdf, page 18

Wind energy output records by region



In the North American Electric Reliability Corporation's (NERC) annual report on threats to grid reliability, the only mention of renewable energy is one paragraph explaining that wind energy is being reliably integrated: "There were no significant reliability challenges reported in the 2011/2012 winter and the 2012 summer periods resulting from the integration of variable generation resources. More improved wind forecast tools and wind monitoring displays are being used to help system operators manage integration of wind resources into real-time operations."[4]

[4] http://www.nerc.com/pa/RAPA/PA/Performance%20Analysis%20DL/2013_SOR_May%2015.pdf, page 47

2. How do grid operators accommodate such large amounts of wind energy?

Variability and uncertainty are nothing new for grid operators, as they have always dealt with large and unexpected fluctuations in electricity supply and demand. Since the days of Thomas Edison, grid operators have had to constantly accommodate variability in electricity demand and supply by increasing and decreasing the output of flexible generators – power plants like hydroelectric dams or natural gas plants that can change their level of generation. Thus, the water kept behind a dam or the natural gas held in a pipeline may be thought of as a form of energy storage, with operators using this energy when it is needed and "storing" it when it is not. For a video illustrating this process, see: https://www.youtube.com/watch?v=gSiCRZcJnfE.

Grid operators have always kept large quantities of fast-acting generation in reserve to respond to the instantaneous and unpredictable failures of large conventional power plants, a challenge and cost that is far greater than accommodating any incremental variability added by the gradual and predictable changes in the aggregate output of a wind fleet. Grid operators use these same flexible resources to accommodate any incremental variability introduced by wind energy that is not canceled out by other changes in electricity supply or demand.

Over the last century, grid operators moved to larger interstate power systems so that changes like an increase in electricity demand caused by a factory coming online would be offset by decreases in electricity demand occurring elsewhere, or an unexpected outage at a power plant could be compensated for by a power plant several states away. The grid remains reliable even though it takes power from many sources that vary over time, just like the Mississippi River takes water from many varying tributaries yet keeps a steady flow into the Gulf of Mexico.

This diversity benefit provides even greater value for wind energy because a region's wind plants are experiencing different weather at any one point in time. Just as a customer in Washington DC turning on their air conditioner is canceled out by a customer in Chicago turning theirs off, output changes at one wind plant are often offset by an opposite change at another wind plant. Furthermore, most output changes for the total wind fleet are canceled out by other changes in electricity supply and demand, mostly by random fluctuations in electricity demand.

Because wind turbines are spread across a large area, it typically takes many hours for a weather event to affect a large share of a region's wind output. Changes in total wind energy output occur very slowly, even though the winds may change fairly rapidly at any one location. The diversity of wind energy output can be seen in this real-time map of wind speeds.[5] NREL's Renewable Energy Futures study, which examined a future in which nearly 50% of electricity is reliably provided by wind and solar, also shows the value of this diversity. For a sample of the study's modeling of hourly electricity supply at nearly 50% wind and solar energy, see: https://www.youtube.com/watch?v=fQl7PS243Dg

Moreover, weather forecasting makes changes in wind energy output predictable, unlike the abrupt outages at conventional power plants that can take 1,000 MW or more offline instantaneously. Wind energy forecasting greatly reduces uncertainty about what wind energy output will be over the next day or more. The use of weather forecasting to reduce uncertainty is also nothing new for grid operators, as grid operators already use weather forecasting to predict how electricity demand will be driven by consumers running their air conditioners or heaters.

[5] http://hint.fm/wind/

Thus, contrary to most people's intuitive experience that winds are highly variable and electricity demand and supply is fairly stable, the opposite is actually true at the grid operator level. Data from the PJM independent grid operator illustrate this fact. The largest hourly changes in electricity demand are typically about 10 times larger than the largest hourly changes in wind energy output, even though PJM has around 6,000 MW of wind energy on its system.[6]

A tremendous amount of flexibility has been built into the power system to accommodate these large and abrupt swings in electricity supply and demand. Demand for electricity can vary by a factor of three or more depending on the time of day and year, which nationwide translates into hundreds of gigawatts of flexibility that are already built into the power system.

Grid operators accommodate variability using different types of "operating reserves," which are provided by flexible resources. As described in more detail under Question 3 below, "regulating reserves" are the fast-acting reserves for accommodating moment-to-moment variability in electricity supply and demand. Grid operators also use fast-acting "contingency reserves" to accommodate unexpected and abrupt failures of large conventional generators. These fast-acting reserves are typically provided by operating power plants changing their level of output.

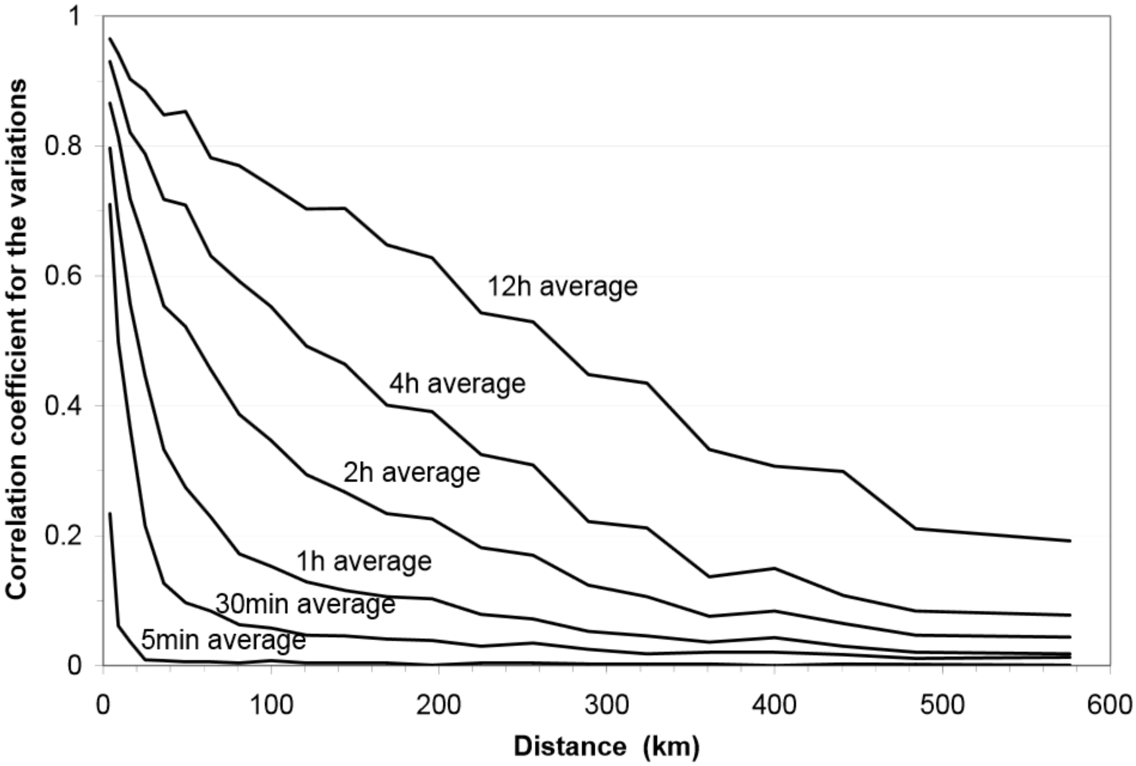
Slower-acting reserves can be provided by a much larger group of resources, often including power plants that are offline but can start up on short notice. These "non-spinning" reserves typically cost far less than the fast-acting reserves provided by operating power plants. This is important because it means that the gradual and predictable changes in wind output are much less costly to accommodate than the instantaneous and unpredictable outages that occur at large conventional power plants, which require grid operators to hold expensive fast-acting reserves 24/7/365.

Several charts derived from wind integration studies and actual grid operating experience help illustrate the variability and uncertainty of wind energy and how they interact with other sources of variability and uncertainty. The first chart shows that as the distance between two wind plants increases, it becomes more likely that their output is not changing in the same direction.[7] This makes sense, because few weather systems are large enough and aligned in such a way that they could affect more than a small number of wind plants simultaneously. As a result, it becomes likely that changes in their output will offset each other. Importantly, the chart shows that for the 5-minute timeframe covered by the fast-acting and most expensive regulating reserves, even a dozen or so miles between two wind plants is enough to make it likely that changes in one wind plant's output will cancel out changes in the other plant's output. This offsetting impact, combined with the fact that electricity demand contributes far more total variability at the 5-minute timescale than wind, explains why wind generation only minimally contributes to the need for fast-acting regulating reserves.

[6] https://www.pjm.com/~/media/committees-groups/task-forces/irtf/20140721/20140721-item-05-wind-report.ashx, http://www.pjm.com/markets-and-operations/energy/real-time/loadhryr.aspx

[7] http://www2.vtt.fi/inf/pdf/tiedotteet/2009/T2493.pdf, page 25

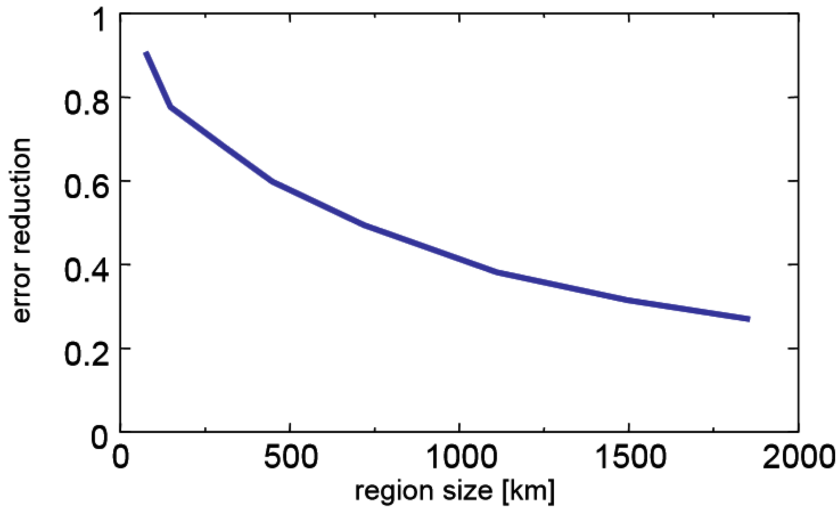
Because wind plant output changes are not correlated across large areas, these output changes cancel each other out



For similar reasons, wind and solar forecast errors also tend to cancel out over larger areas, as shown below. This allows grid operators to more accurately predict changes in wind output and accommodate them at low cost.[8]

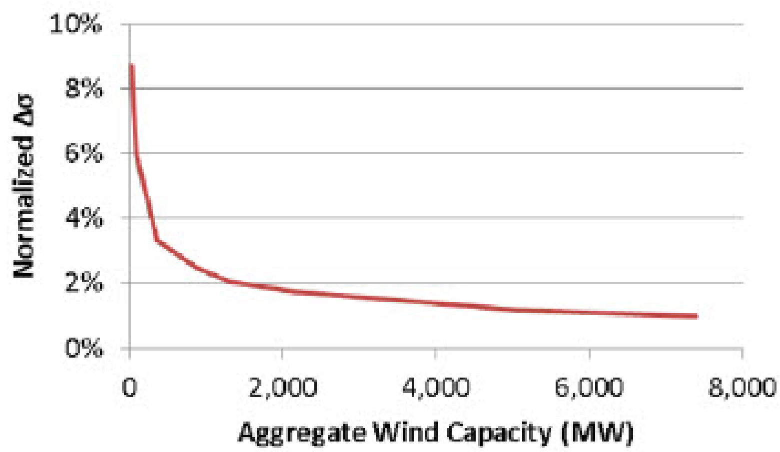
[8] *Ibid.*, pages 26-28

Wind forecast error decreases over larger geographic areas



Because increases in output at one wind plant tend to cancel out decreases in output at others, total wind variability grows more slowly as one adds more wind. Said another way, adding more wind generation increases total wind variability, but tends to reduce the amount of wind variability per MW of installed wind capacity. This is illustrated in the chart below, which shows per-MW wind variability on the y-axis.[9]

Total wind variability grows more slowly as more wind is added

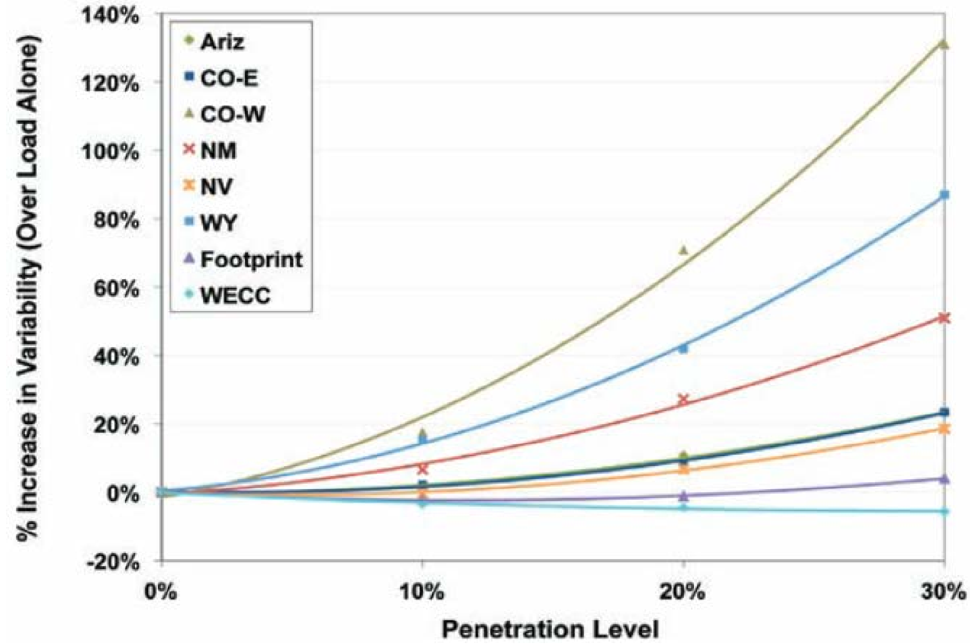


The last chart shows how total system hourly variability changes at higher levels of renewable use. For smaller geographic areas, total system variability grows significantly as renewable variability eclipses electricity demand variability. However, over a geographic area the size of the entire Western U.S., renewable variability cancels out other renewable variability and demand variability to such a large extent that total power system variability actually decreases as one increases to 30% renewable energy use.[10] This geographic diversity drives the benefits associated with coordinating grid operations across larger areas, as discussed in more detail in the answer to Question 10.

[9] http://decarboni.se/publications/western-wind-and-solar-integration-study-phase-2/41-geographic-diversity

[10] Pages 83-84 at http://www.nrel.gov/docs/fy10osti/47434.pdf. "WECC-wide, the variability at 30% penetration is actually *less* than the variability with load alone." [emphasis in original] "The fact that the net load variability at the footprint and WECC level does not significantly increase with penetration speaks volumes about the impact of temporal averaging, geographic diversity and wide-area aggregation on variability."

Change in total power system variability based on renewable use level and size of geographic area



Dozens of grid operator studies and years of real-world operating experience confirm that wind energy only slightly adds to total power system variability, and that most changes in wind energy output are canceled out by opposite changes in electricity supply and demand.[11] Because demand is a far larger contributor to total fast variability, changes in wind output on the minute-to-minute are typically canceled out and have minimal impact on total system fast variability.

Variability in wind and solar does not need to be managed on a stand-alone basis, but rather the grid operator is only concerned about managing the combined variability of all sources of supply and demand. This greatly reduces the cost and challenge of accommodating variability, as the total variability is far less than the sum of its parts. As an analogy, it would be highly inefficient and counterproductive to have a battery or power plant accommodating changes in the electricity demand at your house as you turn appliances on and off, as nearly all of those changes are canceled out anyway by other changes on the aggregate grid, whether caused by your neighbor or someone several states away turning their TV off as you turn yours on.

The table below shows that the regulating reserve need for wind is much smaller than the contingency reserve need for conventional generation. The results are consistent, and surprising. For example, the ERCOT (Texas) and MISO (Upper Midwest) grid operators each reliably accommodate more than 10,000 MW of wind energy on their power systems. These significant levels of wind penetration are being accomplished with limited amount of reserves, with ERCOT finding that amount of wind is reliably accommodated with less than 50 MW of additional fast-acting reserves.[12] ERCOT has also noted that it has been able to integrate renewable energy with a "minimal increase" in operating reserves.[13] Similarly,

[11] http://variablegen.org/resources/
[12] http://variablegen.org/wp-content/uploads/2012/12/Maggio-Reserve_Calculation_Methodology_Discussion.pdf
[13]http://www.ercot.com/content/committees/other/fast/keydocs/2014/ERCOT_AS_Concept_Paper_Version_1.1_as_of_11-01-13_1445_black.doc , page 8

MISO explains that the incremental need for fast-acting reserves due to wind is "little to none."[14] The grid operator for the Great Lakes and Mid-Atlantic states, PJM, holds 3,350 MW of expensive, fast-acting reserves 24/7 in case a large fossil or nuclear power plant unexpectedly breaks down. For comparison, PJM's renewable integration study found that adding more than 28,000 MW of wind only increases the need for these fast-acting reserves by around 360 MW.[15]

The table below focuses on the two fast-acting types of reserves described above, as they are the most expensive types of operating reserves. These two types are also the focus because all grid operators hold regulation and contingency reserves, while the definitions and use of slower-acting reserves vary considerably from grid operator to grid operator, with some not holding these reserves at all but relying on the energy market to provide the needed flexibility.[16] Wind's variability does increase the need for other types of slower-acting, non-spinning reserves, though these reserves are typically much less expensive than regulating reserves. In the next section, a more detailed look at the ERCOT data expands the analysis to include those other types of reserves, and demonstrates that wind's total operating reserve needs are still less costly than the reserve needs for conventional generation.

	MW of wind added	Regulating reserve without wind (MW)	Regulating reserve with wind (MW)	Increase in regulating reserve with wind (MW)	Contingency reserves for conventional generators (MW)
ERCOT actual[17]	10,000	508	550	**42**	**2,800**[18]
MISO actual[19]	10,000	NA	NA	**"Little to none"**	**2,000**
PJM study[20]	28,000	1,204	1,566	**362**	**3,350**[21]
Minnesota study[22]	5,688	137	157	**20**	**660**
Westar actual[23]	400	120.2	123	**2.8**	**NA**

Adding wind energy does affect the operation of other power plants aside from the impact on operating reserve needs. However, the introduction of any new generating resource, particularly a low-marginal cost resource like wind energy, similarly affects the operations of other resources. Moreover, much of this impact is the intentional benefit that wind generation should displace more expensive and polluting forms of energy, and it is difficult if not impossible to disentangle that impact from wind's other impacts on those generators.[24] A further complicating factor is that each grid operator uses different methods for accommodating slower sources of variability and uncertainty, with some using the energy market to

[14] http://variablegen.org/wp-content/uploads/2012/12/Navid-Reserve_Calculation.pdf
[15] http://www.pjm.com/~/media/committees-groups/committees/mic/20140303/20140303-pjm-pris-final-project-review.ashx, page 111
[16] http://apps1.eere.energy.gov/wind/newsletter/pdfs/51978.pdf, page 18
[17] Available at http://variablegen.org/wp-content/uploads/2012/12/Maggio-Reserve_Calculation_Methodology_Discussion.pdf.
[18] http://www.ercot.com/content/news/presentations/2012/Dumas_IPPSA_March13.pdf, page 5
[19] See http://variablegen.org/wp-content/uploads/2012/12/Navid-Reserve_Calculation.pdf, http://www.ferc.gov/CalendarFiles/20140411130433-T1-A%20-%20Navid.pdf
[20] PJM study results, regulation reserve needs in the 14 percent renewable energy scenario, slide 111, available at: http://www.pjm.com/~/media/committees-groups/committees/mic/20140303/20140303-pjm-pris-final-project-review.ashx.
[21] http://www.nrel.gov/docs/fy11osti/47078.pdf, page 141
[22] http://mn.gov/puc/documents/pdf_files/000664.pdf, page xvii
[23] Data submitted to FERC by Westar Energy on February 29, 2012.
[24] http://www.nrel.gov/docs/fy11osti/51860.pdf, pages 6-11

provide the flexibility and others using reserve products. As a result, this paper does not attempt to address those issues beyond what has already been discussed by others.[25]

Returning to the operating reserve table above, a powerful yet under-appreciated mathematical principle explains why wind variability contributes little to total power system variability. Two sources of uncorrelated variability cancel each other out such that the total variability is much less than the sum of the parts. Fortuitously, wind variability and electricity demand variability are uncorrelated at sub-hourly timescales. Mathematically, total variability is the square root of the sum of the squares of the individual variabilities, or sqrt(x^2+y^2). As an example, if the variability of electricity demand is 10 MW and the variability of wind generation is 5 MW, the total variability is not 15 MW, but rather sqrt(100+25) = 11.18 MW. So in this example, adding 5 MW of wind variability only increased total system variability by 1.18 MW, with the other roughly 4 MW of variability canceled out by counteracting demand variability.

The efficiency with which grid operators manage wind variability by aggregating it with all other sources of variability was concisely summed up by an analyst for the International Energy Agency:
"Variability is not just some new phenomenon in grid management. What we found is that renewable energy is not fundamentally different. The criticisms of renewables often neglect the complementarities between different technologies and the way they can balance each other out if spread over certain regions and energy types.

"Grid operators are constantly working to balance available supply with demand – it's what they do. There are always natural variations that cause spikes in demand, reductions in supply or create disturbances in frequency and voltage. Once you see there are a variety of ways to properly manage that variability, you start whittling away at the argument that you always need storage or a megawatt of natural gas backup for every megawatt of renewable energy."[26]

[25] *Id.*
[26] http://thinkprogress.org/climate/2011/06/15/245880/top-5-coolest-ways-companies-are-integrating-renewable-energy-into-the-grid/

3. How much does it cost to integrate wind?

While it is true that wind energy's variability does slightly increase the need for the operating reserves that grid operators use to keep supply and demand in balance, all forms of energy impose integration costs on the power system.[27] In regions with efficient grid operating procedures, by a large margin the most expensive challenge for grid operators is accommodating the abrupt failures of large conventional power plants, not the gradual and predictable changes in wind energy output.

For example, Texas grid operator data show that the operating reserve costs for conventional power plants are far larger than the operating reserve costs for wind generation, even though Texas has more wind energy than any other state and one of the highest levels of wind generation for a U.S. grid operator. The Texas grid operator ERCOT holds[28] 2,800 MW of fast-acting reserves 24/7/365 to keep the lights on in case one of the state's large fossil or nuclear power plants experiences an unexpected failure, as all power plants do from time to time. In contrast, the reserve need for wind is far smaller and can be met with less expensive, slower=acting reserves. The following table compares the reserve costs for wind versus other sources of variability on the ERCOT grid.

Factor	Total annual reserve cost (million $)	% of total reserve cost	Cost per electric bill	Cost per MWh of total/wind generation
Conventional power plant failures	**$239.690**	**67%**	**76 cents**	**$0.65/MWh**
Conventional and demand deviations	**$103.359**	**29%**	**33 cents**	**$0.28/MWh**
Wind	**$13.740**	**4%**	**4 cents**	**$0.37/MWh**

As the table shows, the cost of additional reserves to accommodate wind accounts for about 4 cents out of a typical Texas household's $128 monthly electric bill[29], or 1/30,000th of a typical electric bill. In contrast, the $240 million annual cost of reserves to accommodate conventional power plant failures works out to about 76 cents per monthly electric bill. In other words, the total cost of contingency reserves for conventional power plant failures is more than 17 times larger than the cost of all wind-related reserves.

On a per-MWh of energy produced basis, wind's reserve cost is still about half as large as conventional power plants' reserve costs (1 MWh is roughly the amount consumed by a typical household in a month). Wind's reserve cost is about $0.37/MWh of wind when allocated across the wind MWh generated in ERCOT last year, which equates to roughly 1% of the typical price for 1 MWh of wholesale electricity. In contrast, the cost of contingency reserves was $.65/MWh when allocated across all MWh generated in ERCOT last year, and even higher if only allocated to generation from the larger conventional power plants that cause the need for contingency reserves.[30]

[27] http://www.nrel.gov/docs/fy11osti/51860.pdf, pages 11-16.
[28] http://www.ercot.com/content/news/presentations/2012/Dumas_IPPSA_March13.pdf, page 5
[29] Available at: http://www.eia.gov/electricity/sales_revenue_price/pdf/table5_a.pdf
[30] For more background on these calculations, see http://aweablog.org/blog/post/fact-check-winds-integration-costs-are-lower-than-those-for-other-energy-sources

The table above is directly calculated from the following ERCOT data. The first three rows in the following table list ERCOT data[31] on the incremental amount of reserves it holds to accommodate various sources of variability, while the fourth row lists the average cost of those reserves in 2013, also calculated from ERCOT data.[32] The last three rows use this data to calculate the total reserve cost for each source of variability.

	Regulation down (fast-acting reduction in electric supply)	Regulation up (fast-acting increase in electric supply)	Responsive reserves (contingency reserves)	Non-spinning reserves (slower-acting reserves)
Contingency reserves for conventional power plant failures (MW)			2,800	
Incremental reserves for wind (MW)	14	42		328
Electricity demand variability and deviations at conventional power plants (MW)	476	508		1,474
Average cost of reserve ($/MW)	**$4.89**	**$8.57**	**$9.77**	**$3.47**
Annual reserve cost for conventional power plant failures (million $)			$239.690	
Annual reserve cost for wind (million $)	$0.585	$3.159		$9.996
Annual reserve cost for electricity demand variability and supply deviations at conventional power plants (million $)	$20.372	$38.126		$44.860

The 2- to 3-fold cost premium for faster-acting regulation and responsive reserves versus slower-acting non-spinning reserves is an important driver of the difference in total cost for wind versus conventional. Slower-acting reserves can be provided by a much larger group of resources, often including power plants that are offline but can start up on short notice. These "non-spinning" reserves typically incur far less cost to provide operating reserves than operating power plants, as reflected in the reserve prices shown in the table above. In other regions and under different fuel prices the cost difference can be even more pronounced, with fast-acting reserves sometimes dozens of times more expensive than slower-acting reserves.[33]

[31] Available at: http://variablegen.org/wp-content/uploads/2012/12/Maggio-Reserve_Calculation_Methodology_Discussion.pdf
[32] Data available at http://mis.ercot.com/misapp/GetReports.do?reportTypeId=13091&reportTitle=Historical%20DAM%20Clearing%20Prices%20for%20Capacity&showHTMLView=&mimicKey
[33] http://www.consultkirby.com/files/Ancillary_Services_-_Technical_And_Commercial_Insights_EXT_.pdf, page 30

Moreover, recent analysis by NREL indicates that higher levels of renewable energy may actually decrease the total cost of operating reserves, even though the quantity of operating reserves has increased. Adding renewable generation displaces the output of the most expensive power plants that are currently operating, freeing those generators up to provide reserves and therefore driving down the cost of reserves.[34] As a result, in NREL's analysis of the Colorado and Wyoming power system, total operating reserve costs actually fell from $32.3 million at a 25% renewable penetration to $31.2 million at a 35% renewable penetration, even though the quantity of operating reserves increased.

It is also important to keep in mind that all operating reserve costs are a very small component of the total costs reflected in the average ratepayer's electric bill. For example, total regulation reserve costs account for 0.5% of total PJM wholesale market costs, or about $0.24/MWh.[35] PJM's renewable integration study found that the current amount of renewable generation on its power system increased the need for regulation reserves from 1,204 MW to 1,222 MW.[36] Thus, the incremental regulation reserves needed due to renewable energy accounted for less than 1.5% of 0.5% of total wholesale market costs, or about 4 cents per year for a household that consumes 1 MWh per month. While this calculation does not include slower-acting and less expensive types of operating reserves, it still indicates the very small magnitude of wind-related reserve costs. MISO data show an even lower total cost for operating reserves than PJM.[37]

In short, wind-related reserve costs are a small subset of a small subset of the average ratepayer's electric bill. It is not surprising that the total wind reserve cost was calculated at 4 cents per month for the average Texas customer, even with more than 10,000 MW of wind generation on the main Texas power system.

As addressed later in the answer to Question 10, renewable integration costs may appear to be higher in parts of the country with less efficient grid operating practices, particularly in the Western U.S. However, because these costs would likely be reduced to the levels described above if efficient operating practices were in place, those higher costs should be attributed to the obsolete operating practices that are in place, not renewable generation.

Finally, it should be noted that integration costs for conventional power plants are not assigned to conventional power plant owners, but are rather paid by electricity customers. Wind farm owners can be and are charged for integration costs, while the integration costs for conventional power plants are socialized across consumers' electric bills. As a result, false claims that renewable integration costs will impose a significant burden on customers add insult to injury because conventional generators' far larger integration costs are the ones that are always paid by ratepayers.

[34] http://www.nrel.gov/docs/fy13osti/58491.pdf, page 31
[35] http://www.monitoringanalytics.com/reports/PJM_State_of_the_Market/2013/2013-som-pjm-volume1.pdf, page 12
[36] PJM study results, slide 111, available at: http://www.pjm.com/~/media/committees-groups/committees/mic/20140303/20140303-pjm-pris-final-project-review.ashx.
[37] https://www.misoenergy.org/Library/Repository/Market%20Reports/20140120_sr_ctsl.pdf

4. How much more wind energy can we reliably integrate?

More than a dozen wind integration studies by U.S. grid operators and others have found that wind energy can reliably supply at least 20-30% of our electricity,[38] with some studies analyzing wind providing 40% of total electricity on an annual basis. For example, NREL's Renewable Energy Futures study found no reliability problems for a case in which wind and solar provide nearly 50% of total electricity.[39] A wind integration study by Nebraska utilities found minimal integration costs and no reliability concerns associated with wind providing 40% of electricity in the Southwest Power Pool.[40] As another example, PJM recently studied the impacts of increasing its use of wind energy by a factor of 15, and found the "PJM system, with adequate transmission and ancillary services in the form of Regulation, will not have any significant issue absorbing the higher levels of renewable energy penetration considered in the study."[41]

The Minnesota Department of Commerce just released a comprehensive study that found no challenges to integrating 40% wind and solar energy in Minnesota, including a detailed examination of power system dynamics and other reliability services. The study also found no challenges for accommodating the variability associated with wind and solar providing 50% of electricity in the state, though due to time constraints the study did not include a full analysis of power system dynamics in that case.[42] The International Energy Agency also recently released analysis that examined seven large power systems around the globe, including Texas's, and found that all could reliably and cost-effectively obtain 45% of their electricity from renewable energy.[43] NREL's analyses of over 30% renewable energy penetrations in the Eastern and Western U.S. also found no reliability problems or economic barriers.[44]

It is reasonable to ask whether these studies accurately reflect grid operating realities. Fortunately, the Texas grid operator has answered that question, and in that case found the study actually overestimated the increase in reserve needs that would be caused by wind. In 2013, ERCOT used its real-world grid operating data to validate the results of a 2008 study it had conducted to estimate the impact of higher levels of wind use.[45] The results are summarized in the following table, drawn from the report's graph shown below that.

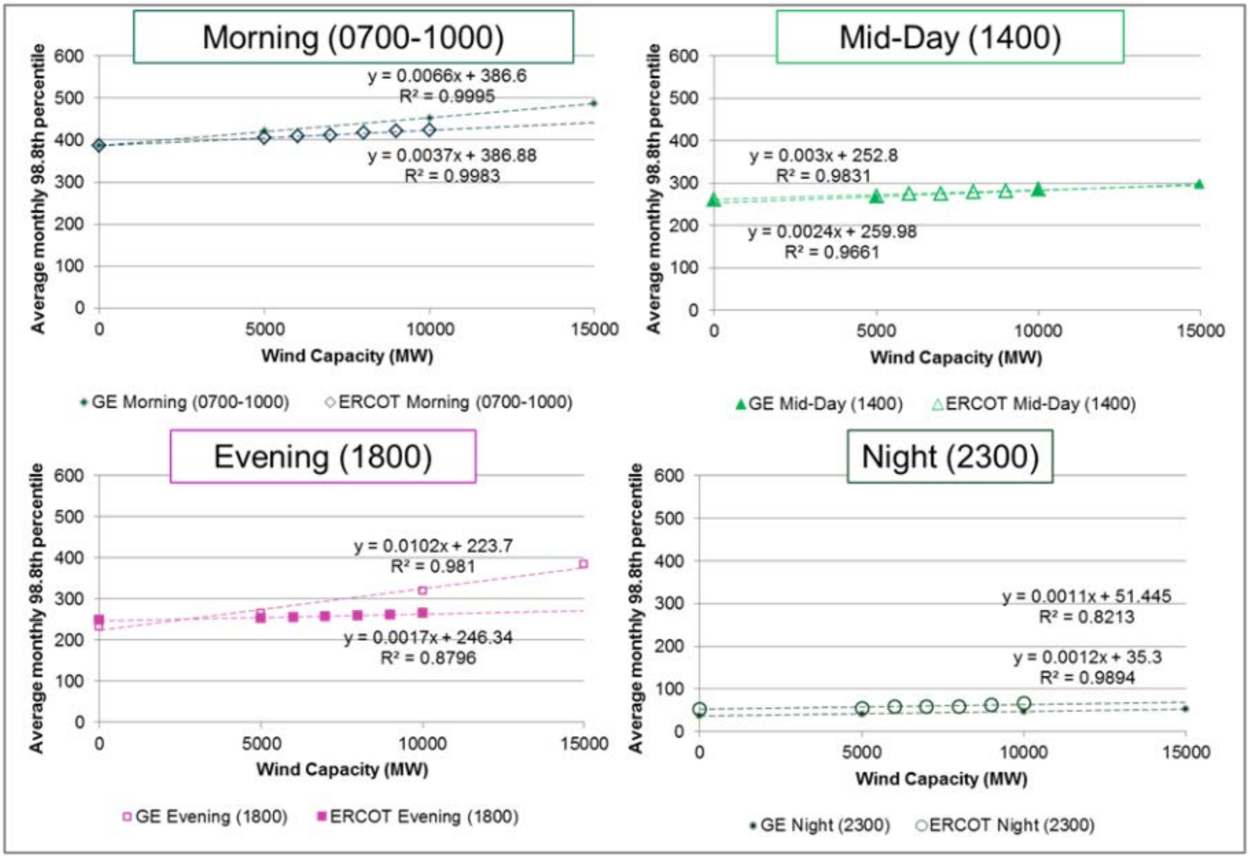
Regulation reserve need per 1,000 MW of wind capacity	**2008 study**	**2012 actual data**
Morning	6.6	3.7
Mid-Day	2.4	3
Evening	10.2	1.7
Night	1.2	1.1
Simple Average	**5.1**	**2.4**

While the 2008 study had predicted that wind would cause a very small increase in operating reserve needs, the actual impact ended up being even smaller. The following graphs from the ERCOT report show

[38] See the library of studies available at http://variablegen.org/resources/#!/3700/u-s-regional-and-state-studies.
[39] http://www.nrel.gov/analysis/re_futures/.
[40] Available at http://www.nepower.org/Wind_Study/final_report.pdf
[41] http://www.pjm.com/~/media/committees-groups/committees/mic/20140303/20140303-pjm-pris-final-project-review.ashx, page 12
[42] https://www.edockets.state.mn.us/EFiling/edockets/searchDocuments.do?method=showPoup&documentId=%7bD607FB96-F80C-49EE-A719-39C411D5D7C3%7d&documentTitle=201411-104466-01.
[43] http://www.iea.org/Textbase/npsum/GIVAR2014sum.pdf
[44] http://www.nrel.gov/docs/fy11osti/47078.pdf, http://www.nrel.gov/electricity/transmission/western_wind.html.
[45] http://www.ercot.com/content/meetings/qmwg/keydocs/2013/1007/GEStudyAnalysis_ERCOTInternalReport.pdf

that the regulation reserve need (y-axis) only marginally increases as the amount of wind increases (x-axis), as most reserves are needed for non-wind variability, even at very high wind penetrations of 15,000 MW.

Increase in ERCOT operating reserve needs as a function of wind capacity



Returning to the question of how high can wind penetration levels go, that is ultimately a question of economics, not reliability. As the use of renewable energy increases, grid operators will simply increase operating reserve levels to ensure that reliability will be maintained at current levels to meet reliability standards. Though as explained above, the incremental cost of these operating reserves is incredibly small, and actually smaller than the integration cost for conventional generation. Moreover, as discussed in the answer to Question 10 below, cost-effective grid operating reforms can provide large amounts of additional flexibility that will enable even higher levels of renewable use.

Grid operating challenges could emerge at very high levels of renewable use, beyond the levels examined in all wind integration studies to date. However, it should be noted that challenges experienced as a power system approaches 100% wind energy have little bearing on the path forward for U.S. grid operators today. Criticizing the challenges in approaching 100% wind energy is an attack on a strawman argument, as no rational voice would call for 100% of electricity supply to be provided by any single energy source, whether it be renewable, coal, gas, nuclear, or anything else.

It is likely that grid operating reforms and holding higher levels of operating reserves could address the challenges associated with extremely high levels of renewable use. The U.S. generation mix is currently evolving towards more flexible resources, which will help address many of those challenges as well. By the time those renewable levels are reached in the U.S., there will likely also have been technological advances in areas such as demand response, energy storage, plug-in vehicles, and even unforeseeable areas that will likely help address these challenges.

It is worth noting that ten years ago, some utilities and grid operators were concerned about the reliability impacts of reaching 5% wind. With greater operational experience and improvements in areas like wind energy forecasting, those concerns have been addressed. This provides reason to be optimistic that improvements in grid operating practices and other areas will continue to make the integration of wind energy even easier.

5. Don't grid operators need to add backup to integrate wind?

No. One of main reasons grid operators built an integrated power system is so that all power plants can back up all other power plants. As explained under Question 2 above, the variability and uncertainty that affect all sources of electricity supply and demand are largely canceled out by other sources of variability and uncertainty. As a result, having a dedicated backup source for each source of variability would be highly inefficient and counterproductive, as counteracting that resource's variability would often increase total power system variability. As an analogy, it would be highly inefficient and counterproductive to have a dedicated resource accommodating fluctuations in the electricity demand at your house, as nearly all of those changes are canceled out anyway by other changes on the aggregate grid.[46]

Moreover, any total power system variability and uncertainty is most efficiently accommodated by the large pool of flexible resources available on the power system. Like any generation resource, wind works best as part of a mix of other resources on the power system. As explained above, a major challenge and expense faced by grid operators is how to keep the lights on when individual power plants break down, as all power plants do from time to time. The challenge is particularly great for failures at large fossil and nuclear power plants, which because of their size can take offline in a fraction of a second enough electricity to supply a large city.

Over the last century, power grid operators have perfected tools for combining hundreds of power plants that are each individually unreliable into a power system that is very reliable. By using most power plants to "back up" all other power plants, grid operators ensure that the lights stay on when even the largest power plant on the grid breaks down. This process works so well that most people are not aware that it occurs, even though the expense of maintaining that backup 24/7 for the unpredictable failure of conventional power plants is quite large, as explained under Question 3 above.

Grid operators typically make a distinction between operating reserves, which were addressed in this answer and the answers above, and "planning reserves," which will be discussed in more detail in the following answer. The primary distinction is that grid operators think about planning reserves on a years-ahead basis when they are deciding what power plants to build, while they think about operating reserves on a day-ahead to real-time basis when they are deciding what power plants to operate. Planning reserves are essentially the cushion of extra power plant capacity that grid operators build so that they will have enough power plants even if some of those power plants are not available on a particular day. For both operating reserves and planning reserves, the answer is that wind can be reliably added at low cost, as the power plant capacity and flexibility that is needed already exists on the power system.

[46] Discussion of pairing dedicated storage or a dedicated "backup" power plant with a particular resource, or combining several resources to create a virtual power plant or a microgrid, often falls into that trap. The power system was built to realize the diversity benefits of having all resources backed up by all other resources and all sources of variability canceling each other out, so dis-aggregating the grid would be a step backwards.

6. What happens when the wind doesn't blow?

Other plants provide energy at those times, in the same way that all power plants back up all other power plants. Portfolio diversity is the key, as no resource is available 100% of the time and all power plants are dependent on all others to back them up. Grid operators build more than enough power plant capacity to meet electricity demand, so that a "reserve margin," or cushion is available in case some power plants are not available.

Adding wind power never increases the need for power plants, but rather reduces it. No new capacity is needed to integrate wind, as wind's contribution to meeting system capacity needs is always positive.[47] A power system's capacity need is a total system need driven by peak demand, so that total need does not change based on the amount of wind power on the system.

Wind does make valuable contributions to meeting the power system's need for capacity. Because of the geographic diversity described in the answer to Question 2 above, a region's aggregated wind energy fleet produces power almost all of the time, particularly when diverse wind resources are aggregated over a very large area. In some regions, such as coastal areas and some mountain passes, wind output is typically highest when electricity demand is highest. Moreover, as described in more detail below, wind energy is a critical part of creating a more diverse energy mix to protect against the type of "common mode" simultaneous failure that can affect any type of generation, often in unforeseen ways.

Regardless of a region's wind energy output profile, grid operators plan for the capacity value provided by wind like any other resource, and by using the same statistical tools.[48] These tools account for each resource's contribution to the need for on-peak capacity and ensure there is sufficient cushion based on the expected availability of each resource. Wind energy is typically readily incorporated into that calculation.

This calculation accounts for the fact that no power plant is perfectly controllable, and in fact many resources also fail to produce their maximum capacity when electricity prices are highest. Most thermal power plants experience significant de-rates in their efficiency and maximum output when ambient air temperatures are high, which typically coincides with the time periods when electricity demand and prices are at their highest. DOE data show that the U.S.'s gas, oil, coal, and nuclear fleets have "summer capacities" that are 87%, 89%, 92%, and 95% respectively of their nameplate capacities. In addition, all power plants occasionally experience forced outages that unexpectedly take them offline, and these outages tend to happen with higher frequency during weather extremes that drive high electricity demand. As discussed below, a prime example is the unexpected failure of more than 20% of PJM's conventional power plants during extreme cold and electricity demand in January 2014.[49]

As explained in the next section, grid operators only need a certain amount of flexibility to operate the power system, so it is not necessary for all resources to be operated in a "dispatchable" manner so that their output can be changed to accommodate changes in electricity supply and demand. Wind plants can be operated dispatchably if necessary, but it is not typically economic to do so as other resources can provide that dispatchability at lower cost. This situation is very similar to that of "baseload" conventional resources: because both types of resources can provide low cost energy, it typically does not make economic sense for them to forgo energy production so they can provide flexibility.

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[47] See page 2 at http://www.nrel.gov/docs/fy11osti/51860.pdf
[48] http://www.nrel.gov/docs/fy08osti/43433.pdf
[49] http://www.pjm.com/~/media/documents/reports/20140509-analysis-of-operational-events-and-market-impacts-during-the-jan-2014-cold-weather-events.ashx

It should also be noted that most U.S. power systems currently have a surplus of capacity. For those that do not, additional capacity can be obtained at relatively low cost through demand response and energy efficiency, the 45+ GWs of new gas generation that is already being built,[50] or even retaining some existing generating capacity. Retaining capacity is often an attractive option, as doing so only incurs a plant's ongoing fixed costs and does not significantly affect emissions because emissions are a product of energy production, not maintaining capacity.

Energy costs are a far larger component of consumers' electric bills than capacity costs. The value recovered in PJM's separate capacity market is only about 1/6 of the total value recovered in the energy market.[51] This is confirmed by comparing the very large total production cost of the power system, which is largely composed of fuel costs, versus the far smaller annualized capital cost of total power plant capacity levelized over the very long lifetime of those assets.

Given recent events in which many conventional power plants of the same type experienced unexpected simultaneous "common mode" failures, portfolio diversity is also becoming an increasingly important consideration. Wind energy provides significant value by diversifying our electricity mix to makie it more reliable.

The portfolio diversity benefits of wind energy were particularly pronounced last winter as unexpected generator failures and fuel price spikes caused electricity prices to soar as many regions faced record winter demand. Wind energy continued to produce at or above expectations with no exposure to fuel price increases. The consumer savings from stably-priced wind generation totaled at least $1 billion over two days in PJM alone, and wind helped to avert potentially severe reliability problems.[52] During another cold snap in early January 2015, wind energy similarly provided record amounts of power to grid operators in the Central and Eastern U.S. as they faced high demand due to extreme cold.[53] These events illustrate how wind plays a critical role in protecting consumers and reliability by diversifying our energy mix:

- Early on January 6, 2014, the Nebraska Public Power District met record winter electricity demand with wind providing about 13% of its electricity. The utility explained that "Nebraskans benefit from NPPD's diverse portfolio of generating resources. Using a combination of fuels means we deliver electricity using the lowest cost resources while maintaining high reliability for our customers." The utility also noted that "NPPD did not operate its natural gas generation because the fuel costs were up more than 300 percent over typical prices."[54]
- On January 7, 2014, wind output was very high when the New York grid operator faced record winter demand.[55]
- On January 22 and 23, 2014, PJM electricity and natural gas prices skyrocketed to 10-50 times normal due to extreme cold. Wind output was above 3,000 MW, saving consumers millions.[56]
- As "a shortage of natural gas triggered by extreme cold weather" affected California on February 6, 2014, wind energy provided the state with around 2,000 MW at the time of peak demand, with

[50] www.nerc.com/pa/RAPA/ra/Reliability Assessments DL/2014LTRA_ERATTA.pdf, page 18
[51] http://www.monitoringanalytics.com/reports/PJM_State_of_the_Market/2013/2013-som-pjm-volume1.pdf, page 12
[52] http://awea.files.cms-plus.com/AWEA%20Cold%20Snap%20Report%20Final%20-%20January%202015.pdf
[53] http://www.utilitydive.com/news/wind-generation-hits-records-mitigates-price-spikes-during-cold-snap/351057/
[54] http://www.nppd.com/2014/nebraska-customers-set-time-winter-peak-nppd/
[55] http://www.nyiso.com/public/webdocs/media_room/press_releases/2014/NYISO%20-%20Frigid%20Temperatures%20from%20Polar%20Vortex%20Drive%20Record%20Winter%20Demand%20-%2001_09_14%20-%20FINAL.pdf
[56] http://www.pjm.com/markets-and-operations/ops-analysis.aspx

wind output above 2,500 MW for most of the rest of the evening.[57] The state grid operator noted that this wind output allowed it to avoid calling an energy emergency alert.[58]

NERC recently released its Polar Vortex Review.[59] This report identified fuel deliverability issues, natural gas pipeline outages, gas service interruptions, and frozen electricity and gas equipment as key factors for generator unavailability during the vortex, which threatened system reliability in multiple regions. While wind turbines did occasionally experience outages due to the cold weather, the vast majority of the generators that failed to perform were conventional power plants.

The story was the same in February 2011, when ERCOT noted wind energy's role in keeping the lights on when a cold snap caused many conventional power plants to fail.[60] Notable examples of wind improving reliability by increasing the diversity of the energy mix have also occurred in other countries.[61]

The portfolio diversity benefits of renewable energy can also be seen in how wind and solar have helped to cost-effectively maintain electric reliability during the California drought over the last year, making up[62] for the vast majority of the 1/3 decline in hydroelectric output.[63]

While the drought is imposing major costs on the state's agriculture and Californians in general, the drought also poses challenges for electric reliability because the U.S. electricity system is so heavily dependent on water. The California grid operator expected 1,370 MW to 1,669 MW (18-22 percent) of the state's 7,666 MW of hydroelectric power plants to be unavailable to provide energy to meet peak system demands during the summer of 2014.[64] Moreover, the grid operator noted that 1,150 MW of the state's thermal power plants were at risk of having cooling water supply curtailments that summer.

Renewable energy is helping with this challenge in two direct ways. One of wind energy's most overlooked benefits is that it requires virtually no water to produce electricity, while almost all other electricity sources evaporate tremendous amounts of water. In 2008, the nation's thermal power plants consumed 1 to 2 trillion gallons of water.[65] By displacing generation from these conventional power plants, U.S. wind energy currently saves around 35 billion gallons of water per year, the equivalent of 120 gallons per person or 285 billion bottles of water.[66]

In addition to directly offsetting freshwater consumption at thermal power plants, wind energy helps combat the impacts of drought by allowing grid operators to save hydroelectric energy (in the form of water behind dams) until they need it to meet grid reliability needs. A MWh of wind energy almost always displaces a MWh that would have been produced by a fossil-fired power plant, though sometimes grid operators use wind energy to store additional water behind dams where it can be used later to displace fossil fuel generation. While a number of complex factors affect how dams use their water resources, the abundant supply of renewable energy likely alleviated pressure on the operators' need to use water to

[57] http://www.caiso.com/Documents/ISOissuesStatewideFlexAlert.pdf
[58] SNL Energy article, Christine Cordner, "CAISO: Wind, demand response helped avoid February emergency alert," March 21, 2014
[59] Available at: http://www.nerc.com/pa/rrm/January%202014%20Polar%20Vortex%20Review/Polar_Vortex_Review_29_Sept_2014_Final.pdf
[60] Available at: http://www.texastribune.org/2011/02/04/an-interview-with-the-ceo-of-the-texas-grid/
[61] http://thinkprogress.org/climate/2014/08/12/3470140/wind-power-nuclear/
[62] http://www.eia.gov/electricity/monthly/epm_table_grapher.cfm?t=epmt_1_14_b
[63] http://www.eia.gov/electricity/monthly/epm_table_grapher.cfm?t=epmt_1_13_b
[64] http://www.caiso.com/Documents/2014SummerAssessment.pdf
[65] http://www.ucsusa.org/assets/documents/clean_energy/ew3/ew3-freshwater-use-by-us-power-plants.pdf
[66] http://www.awea.org/windandwater

produce electricity, helping them maintain reservoir levels so they could continue producing power and providing grid reliability services. In addition, in most regions the variability of the wind energy resource from year-to-year is much lower than that of the hydroelectric resource, so adding wind energy improves the reliability and resilience of the electricity system, particularly in regions that obtain a large share of their electricity from hydropower.[67]

[67] http://www.nwd-wc.usace.army.mil/PB/Workshop/6-PS-CEAtech3TIER2.pdf

7. Don't we need baseload power?

Instead of using the term "baseload," it is more insightful to talk about the three main services the grid needs to operate reliably: energy, capacity, and flexibility. Cost-effectively obtaining all three services requires a division of labor among a diverse mix of energy sources, as no resource excels at providing all three. For example, baseload resources typically do not provide flexibility, and there can be lower-cost ways of obtaining the energy and capacity provided by baseload. Wind energy primarily adds value to an energy portfolio as a low-cost and non-polluting source of energy, though it also provides some capacity and can provide flexibility when it is economic to do so.

Reliable and cost-effective operation of the electric grid requires a mixture of three types of resources: energy (electricity), capacity (ability to generate electricity at a certain point in time), and flexibility (ability to "turn up" or "turn down" electricity generation as needed).

The following table lists the ability of different types of power plants to provide the attributes of energy, capacity, and flexibility. A power plant may specialize in providing one or two of these power system needs, but no power plant excels at providing all three.

	Energy	Capacity	Flexibility
Wind	X+	Some	Can, but is costly
Nuclear	X	X	None
Coal	X	X	Little
Natural gas comb. cycle	X-	X	X
Natural gas turbine	Too costly	X+	X+
Hydroelectric	Some	X	X

Because of these differing capabilities, it is important to have a diversity of generation resources on the power system. The most efficient strategy is generally for resources to provide the services they can provide at low cost, and not try to use one type of resource to provide all services.

The power system's current trend towards a greater use of renewable energy, gas generation, and demand response appears to be a cost effective way to meet all three power system needs. Renewable energy is an ideal source of low-cost energy, while gas generation and demand response provide capacity and flexibility at low cost.

This kind of "division of labor" is not new, as it has long been the most economic way to provide all of the services needed to keep the lights on. As shown in the table above, each of the various types of power plants on the grid today may have low costs for providing one or two of those services, but no power plant is the most economic source in all three categories.

As the table illustrates, wind excels at providing energy, as its fuel source is free. Wind does provide some capacity and can provide flexibility, although it is typically not the most economic choice if one is primarily seeking to obtain larger amounts of those services.

Renewables do provide valuable amounts of firm capacity for meeting system needs, and this can be accounted for using the same statistical tools planners use for other resources.[68] Wind typically provides

[68] http://www.nrel.gov/docs/fy08osti/43433.pdf

capacity in a ratio of about one unit of capacity for every two units of average energy output,[69] though a wind plant's exact amount of capacity varies depending on a number of site-specific factors. Wind plants can also rapidly and precisely reduce their output on command, giving them excellent flexibility for reducing supply. Flexibility to increase power supply is much more costly for wind plants, as doing so requires holding the plant below its potential output, sacrificing a significant amount of energy that could have been produced for free. However, in certain circumstances in can be economic to do so, and the speed and accuracy of response is higher than almost any other resource.[70]

Nuclear and coal plants, conventionally thought of as "baseload" plants, are remarkably similar to wind plants in that they are primarily energy resources. Like wind, their fuel costs and operating costs are very low. Nuclear and coal plants are capable of providing capacity at a level close to their maximum output. Even so, no power plant can be counted on to reliably provide capacity at its maximum output, as all plants experience mechanical, electrical, or other failures from time to time and must go offline with little notice. For example, nuclear power plants in the Southeastern U.S. have been forced to shut down, some for periods of several weeks, because drought and summertime heat waves raised the temperature of the water in the rivers they rely on for cooling their steam generators.

Almost all nuclear plants in the U.S. provide no flexibility, and the flexibility provided by some coal plants can be limited. A primary factor is the same reason why most wind plants are not used to provide flexibility: because these resources can provide low cost energy, it typically does not make economic sense for them to forgo energy production so they can provide flexibility.

Electricity supply and demand has always fluctuated, so grid operators have learned to use a division of labor that uses the most flexible resources for flexibility while other resources provide little to no flexibility. Thus, concern expressed by some that wind plants are not typically operated in a dispatchable way is unfounded. Many types of power plants, including most baseload power plants, are not operated in a dispatchable way today, yet power system reliability is maintained. Like baseload resources, wind can be operated dispatchably, it is just not typically economic to do so.

A power system with only baseload resources would not be reliable or cost-effective, and moreover other resources can provide all of the services that are currently provided by baseload generators, in many cases at lower cost than the baseload generators. Baseload resources are not, by themselves, either necessary or sufficient to provide all of the services the power system needs

Natural gas power plants are generally the opposite of nuclear and coal plants, providing significant amounts of flexibility and capacity but typically less energy.[71] This is not because natural gas plants are incapable of generating large amounts of energy, but rather due to the fact that gas power plants typically have higher operating costs because natural gas is generally more expensive than coal.

However, gas plants, particularly combustion turbine (CT) plants, do excel at providing capacity and at changing their output rapidly. Combined-cycle (CC) natural gas plants are more efficient and thus have lower operating costs than combustion turbine plants, but the tradeoff is that they are generally less

[69] A typical wind plant's average energy output is 30-40% of the nameplate rating (**capacity factor**), while a typical **capacity value** (how much of the wind plant's capacity can be counted on for meeting electric demand) is 15-20% of the nameplate rating.

[70] http://www.nrel.gov/electricity/transmission/pdfs/wind_workshop2_13bartlett.pdf

[71] http://www.eia.gov/electricity/monthly/epm_table_grapher.cfm?t=epmt_6_07_a

flexible. Gas combustion turbines excel at providing capacity at low cost, with a plant's capacity value typically many times higher than its average capacity factor.

Hydroelectric plants are capable of being used for energy, capacity, or flexibility, but there are tradeoffs between these that limit any one dam from providing significant amounts of all three during the same period of time. For example, an increase in the dam's energy and capacity output causes a decrease in its flexibility, and vice versa. In addition, there are also tradeoffs between energy and capacity, because using up the water stored behind the dam to provide energy limits the ability to provide capacity at a later time.

Our current power system successfully balances the need for energy, capacity, and flexibility. However, the need to reduce carbon dioxide emissions and reduce our dependence on fossil fuels is driving changes in our energy mix. Because carbon emissions and fuel use are a product of the amount of energy produced, these are not capacity or flexibility challenges, but rather energy challenges. Wind energy, being predominantly an energy resource, is ideally suited to help solve these challenges.

Of course, the grid will continue to need capacity and flexibility. As explained above, wind energy can provide these resources to some extent, although not as well as other types of power plants. Fortunately, natural gas power plants can provide capacity and flexibility at very low cost. Building more natural gas plants or keeping existing fossil-fired power plants around does not significantly harm efforts to reduce fossil fuel use, as power plants that are being used to provide capacity and flexibility only run during the small number of hours per year when those services are needed. Demand response, in which electricity consumers reduce or delay non-essential electricity use in response to price signals, can also be used to provide capacity and flexibility at very low cost. Plug-in electric vehicles also have significant potential to serve as sources of flexibility.

Increasing the amount of wind energy and other variable renewable resources on the grid is likely to decrease the need for baseload power. Why? As explained above, wind and baseload plants are both primarily energy resources. In addition, neither is an ideal source of capacity or flexibility. Inflexible baseload plants can actually be a significant impediment to the growth of wind energy, as the inability to turn baseload plants off during periods of low electric demand can cause the supply of electricity to exceed demand. This can cause an inefficient outcome in which wind plants must employ their superior flexibility and reduce their output, wasting free, zero-emissions energy.

Discussion of what power system resources are needed should be focused on the specific services the power system needs and finding the optimal mix for obtaining those services at the lowest cost and with the lowest fuel price risk to consumers.

8. What about the reliability services provided by conventional generation?

As wind energy has grown to provide a larger share of our electricity mix, wind turbine technology has matured so that modern wind plants are able to provide the same grid reliability services as conventional generators. As the North American Electric Reliability Corporation (NERC) has stated, "This issue does not exist for utility-scale wind energy, which offers ride-through capabilities and other essential reliability services,"[72] and "Modern wind turbine generators can meet equivalent technical performance requirements provided by conventional generation technologies with proper control strategies, system design, and implementation."[73] Detailed analyses show that essential reliability services will be maintained at high renewable levels in both the Eastern and Western Interconnections.[74] Wind plants can provide frequency response, inertial response, active power control, voltage and frequency ride-through, voltage and reactive power control, and other grid reliability needs:

Reliability service	**Wind**	**Conventional generation**
Ride-through	- Excellent voltage and frequency ride-through per FERC Order 661A requirements - Power electronics electrically separate wind turbine generators from grid disturbances, providing them with much greater ability to remain online through disturbances	- Many cannot match wind's capabilities or meet Order 661A ride-through requirements
Reactive and voltage control	- Wind turbine power electronics provide reactive and voltage control equivalent to that of conventional generators[75] - Power electronics can provide reactive power and voltage control even when the wind plant is not producing power[76] - Because reactive needs are location-specific on grid, 661A approach of providing reactive in locations where it is needed is more efficient than blanket requirement	- Provides
Active power control	- Can provide extremely fast response in seconds, far faster than conventional generation[77] - Like other generators, wind will provide this response when it is economic to do so - Xcel Energy sometimes uses its wind plants to provide some or all of its frequency-responsive automatic generation control[78]	- Like wind, many baseload generators do not provide active power control for economic reasons, though they technically can

[72] http://www.nerc.com/pa/RAPA/ra/Reliability%20Assessments%20DL/2014LTRA_ERATTA.pdf at 15
[73] http://www.nerc.com/files/ivgtf_report_041609.pdf, page 22
[74] http://www.nrel.gov/docs/fy15osti/62906.pdf, http://www.nrel.gov/docs/fy13osti/58077.pdf
[75] http://www.nerc.com/files/ivgtf_report_041609.pdf, page 22, "As variable resources, such as wind power facilities, constitute a larger proportion of the total generation on a system, these resources may provide voltage regulation and reactive power control capabilities comparable to that of conventional generation. Further, wind plants may provide dynamic and static reactive power support as well as voltage control in order to contribute to power system reliability."
[76] http://energy.sandia.gov/wp/wp-content/gallery/uploads/ReactivePower_IEEE_final.pdf
[77] http://www.nrel.gov/electricity/transmission/active_power.html "Wind power can act in an equal or superior manner to conventional generation when providing active power control, supporting the system frequency response and improving reliability."

Frequency response	-Adding wind can help system frequency response by causing conventional generation to be dispatched down[79]-Wind can provide frequency response, but it is typically more costly for it to do so than for other resources as it requires curtailing wind generation in advance[80] -A market-based solution would procure frequency response from the lowest cost resources	- Changes in conventional generator operating procedures have greatly reduced frequency response[81] - Only 70-75% of generators have governors that are capable of sustaining frequency response for more than one minute, and about half of conventional generators have controls that may withdraw sustained frequency response for economic reasons[82] - "Only 30% of the units on-line provide primary frequency response. Two-thirds of the units that did respond exhibit withdrawal of primary frequency response." So, "Only 10% of units on-line sustain primary frequency response."[83] - The cost of providing and sustaining frequency response is very low for a conventional generator, so a market-based solution would incentivize the needed frequency response at low cost
Inertial response	-Can provide with no lost production by using power electronics and the inertia of the wind turbine rotor; this capability is commercially available but not widely deployed because there is no payment for any resource to provide this service[84]	-Provides
Increases need for operating reserves, integration cost	- Very small impact on total reserve need and integration cost	-Contingency reserve needs and costs are quite large

As documented in the footnotes in the table above, many NERC reports discuss the capabilities of renewable energy to provide these reliability services. For example, NERC reports have documented that wind and solar "may provide voltage regulation and reactive power control capabilities comparable to that

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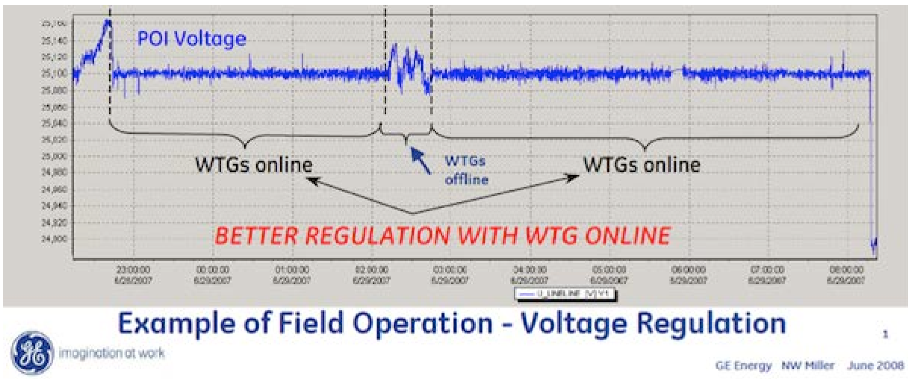
[78] http://www.nrel.gov/electricity/transmission/pdfs/wind_workshop2_13bartlett.pdf
[79] http://www.nerc.com/pa/RAPA/ra/Reliability%20Assessments%20DL/2014LTRA_ERATTA.pdf at page 29, "However, by causing conventional generators to have their output dispatched down, wind and solar generation can increase generator headroom and, therefore, the amount of total frequency response being provided."
[80] *Id.*, "Wind resources can offer inertia and frequency response, depending on the design attributes of a given wind plant."
[81] http://www.nerc.com/files/FinalFile_Comments_Resp_to_Sept_Freq_Resp_Tech_Conf.pdf
[82] http://www.nerc.com/docs/pc/FRI_Report_10-30-12_Master_w-appendices.pdf, pages 32-33
[83] *Ibid.,* page 37
[84]http://web.mit.edu/windenergy/windweek/Presentations/GE%20Impact%20of%20Frequency%20Responsive%20Wind%20Plant%20Controls%20Pres%20and%20Paper.pdf; http://www.nerc.com/files/ivgtf_report_041609.pdf, page 18, "In common with Type 3 wind turbine-generators, this decoupling means that in the standard design inertial response can be a programmed feature during a frequency event and the Type 4 wind turbine-generators can provide comparable inertial response/ performance to a conventional generator."

of conventional generation."[85] All modern wind turbines have sophisticated power electronics that allow the turbine to provide significant voltage and reactive power control at all times, even when the wind turbine is not producing electricity. As compellingly illustrated by the actual power system data presented in the chart below,[86] wind turbines can significantly improve power system voltage stability, indicated by the fact that power system voltage is much better regulated when wind turbine generators (WTGs) are online than when they are not.



Thanks to their power electronics, wind plants also meet a higher standard for and far exceed the ability of conventional power plants to "ride-through" power system disturbances, which is essential for maintaining reliability when voltage and frequency disturbances occur, such as when large conventional power plants experience forced outages.[87] Regarding inertia and system stability, analysis by WECC in 2013 found that in a scenario with very high renewable penetration across the West, "the system results did not identify any adverse impacts due to the lower system inertia or differently stressed paths due to the higher penetration of variable generation resources."[88]

Analysis conducted for the California grid operator identified no major concerns for frequency response in a transition to a high renewable future, finding that "[n]one of the credible conditions examined, even cases with significantly high levels of wind and solar generation (up to 50% penetration in California), resulted in under-frequency load shedding (ULFS) or other stability problems."[89] Adding wind generation can increase total power system frequency response by causing conventional power plants to have their output reduced, which provides them with more range to increase their output and provide frequency response.[90]

In addition, new techniques employing wind plants' sophisticated controls and power electronics enable wind plants themselves to provide fast-acting frequency response. NREL recently released in-depth analysis that concluded "wind power can act in an equal or superior manner to conventional generation when providing active power control, supporting the system frequency response and improving

[85] NERC, "Accommodating High Levels of Variable Generation," April 2009, available at http://www.nerc.com/docs/pc/ivgtf/IVGTF_Report_041609.pdf, page 22.
[86] Miller, N., GE Presentation, June 2008.
[87] FERC Order 661A provides strict ride-through requirements for wind turbines, requirements that do not apply to conventional generators and that many conventional generators are unable to meet. http://www.ferc.gov/whats-new/comm-meet/052505/E-1.pdf
[88] Available at http://www.wecc.biz/committees/StandingCommittees/PCC/RS/RPEWG%20-%20RS%20Meetings8-21-13/Lists/Minutes/1/VGSStudy7-15-13.doc
[89] Available at http://www.caiso.com/Documents/Report-FrequencyResponseStudy.pdf
[90] http://web.mit.edu/windenergy/windweek/Presentations/GE%20Impact%20of%20Frequency%20Responsive%20Wind%20Plant%20Controls%20Pres%20and%20Paper.pdf

reliability."[91] The report further documented how major utilities like Xcel Energy are using this capability of wind plants in some hours to provide some or all of the frequency response and regulation needed to maintain power system reliability, which has enabled Xcel's Colorado power system to at times reliably obtain more than 60 percent of its electricity from wind energy.[92]

NREL also performed studies[93] on frequency response in the Eastern and Western Interconnections for scenarios with high wind energy penetration, which found adding wind generation is unlikely to significantly reduce frequency response and can actually improve it.

It should also be noted that many conventional generators currently provide little to no frequency response.[94] NERC has explained that a failure of conventional generators to provide frequency response is the primary cause of observed declines in system-wide frequency response, while NERC explicitly notes that the growth of wind and solar is not responsible for the decline.[95] This is important to note because some have attempted to claim that conventional resources inherently provide essential reliability services while renewable resources have little to no ability to provide these services. As explained above, both claims are incorrect. Not only are there many counterexamples, but in many cases renewable resources actually exceed conventional resources in their ability to provide and in their provision of essential reliability services.

It is also important to remember why the power system needs frequency response and ride-through services in the first place. The ability to ride-through voltage and frequency disturbances is needed in large part because large conventional power plants cause frequency and voltage excursions when they unexpectedly fail, though transmission line failures can also cause these disturbances. Frequency response is also primarily needed so that the grid can reliably accommodate the unexpected failure of large conventional power plants. Because large conventional power plant failures occur so abruptly, often in a fraction of a second, the response from other power plants must also occur very quickly. Through frequency response, power plants are programmed to immediately increase their output when they automatically sense that a large conventional power plant has failed. Thus, it is doubly frustrating that some have incorrectly blamed wind energy for contributing to a problem that is actually caused by conventional power plants choosing not to provide the frequency response that is needed primarily because of the abrupt failures of other conventional power plants.

Because different resources face drastically different costs for providing services like frequency response, a market is by far the most efficient solution for procuring these services. This is particularly true because, as discussed in the NERC document cited above, many conventional generators can provide frequency response at low cost but have opted not to because there is no financial incentive to do so. In contrast, requiring the provision of this and other services from all generators, such as through a blanket requirement written into interconnection standards, would unnecessarily impose major costs by requiring resources that cannot cost-effectively provide these services to do so.

Markets would also appropriately incentivize resources that can cost-effectively provide these services to do so. For example, technology that allows wind turbines to provide inertial response is commercially available, but purchasers are not asking for them because there is no financial incentive for providing these services. Similarly, while under most conditions it may not be cost-effective for wind generators to provide

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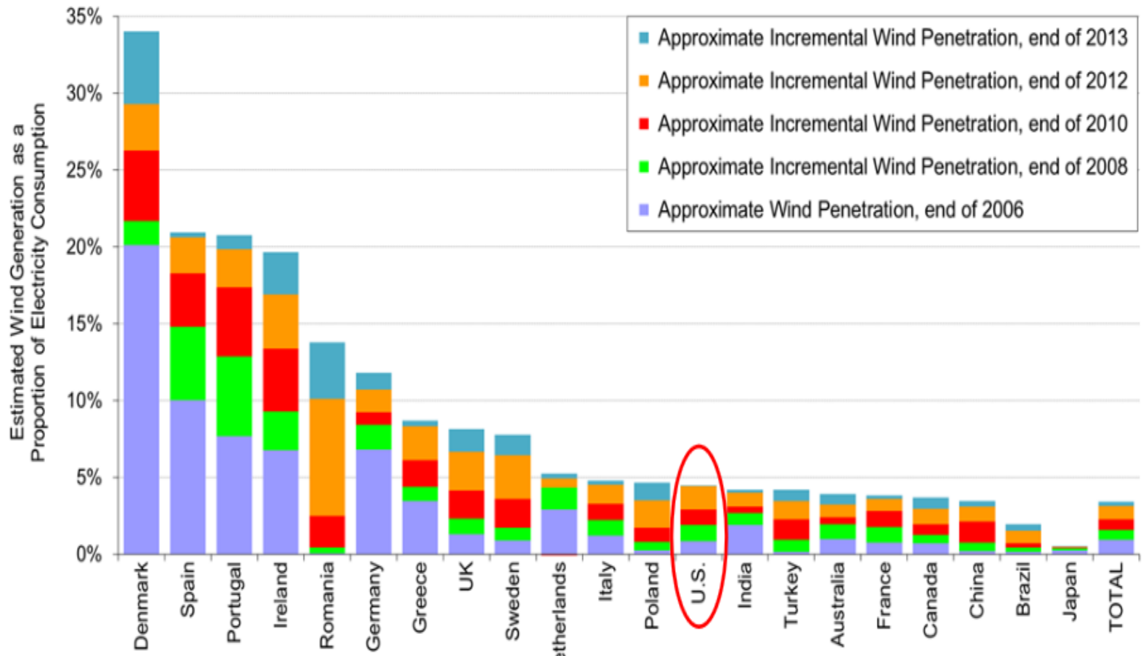
[91] Available at http://www.nrel.gov/docs/fy14osti/60574.pdf
[92] http://www.nrel.gov/electricity/transmission/pdfs/wind_workshop2_13bartlett.pdf
[93] Available at: http://www.nrel.gov/docs/fy13osti/58077.pdf, http://www.nrel.gov/docs/fy15osti/62906.pdf
[94] *Ibid.,* page 37
[95] http://www.nerc.com/files/FinalFile_Comments_Resp_to_Sept_Freq_Resp_Tech_Conf.pdf

frequency response, a market would send the appropriate price signal and ensure that the least-cost resources are selected to provide these services.

9. What has been Europe's experience with renewable energy?

European nations have demonstrated that wind energy can reliably provide an even larger share of generation, with Ireland, Spain, and Portugal obtaining around 20% of their electricity from wind on an annual basis, and Denmark at nearly 35%.[96] Including solar and other renewable energy sources, Germany, Spain, and Portugal obtain over 25% of their electricity from non-hydro renewable resources.



Wind energy leaders Denmark, Ireland, Spain, and the Netherlands all have some of the most reliable power systems in the world, and they have seen their reliability improve significantly as they have increased their use of wind energy.[97] Germany's power system is the most reliable in Europe, and it has grown even more reliable as Germany has greatly increased its use of renewable energy in recent years.[98] Germany's reliability score is 16 times better than that of the US, and four times better than that of France. This is not to claim that renewables are the cause of the high reliability in these countries, as the most important factor in preventing customer outages is the resilience of the low-voltage distribution system for preventing localized outages. However, the data clearly does not support the claim that increasing use of wind energy has harmed European electric reliability, particularly the dubious claim that localized reliability problems have been caused by wind energy.[99]

These countries' carbon emissions have also drastically decreased as they have ramped up their use of renewable energy over the last decade, disproving the myth[100] that European expansion of renewable

[96] http://emp.lbl.gov/sites/all/files/2013_Wind_Technologies_Market_Report_Final3.pdf, page 8, circle added to note the U.S.
[97] http://cleantechnica.com/2012/09/12/german-grid-reaches-record-reliability-in-2011-thanks-to-renewables/
[98] http://spectrum.ieee.org/energywise/energy/the-smarter-grid/germanys-superstable-solarsoaked-grid
[99] For an example of the false claims being made about European reliability, mostly by fossil fuel industry-supported groups, see http://instituteforenergyresearch.org/analysis/germanys-green-energy-destabilizing-electric-grids/
[100] http://instituteforenergyresearch.org/analysis/germanys-renewable-energy-transition-misses-carbon-reduction-goals/

energy has not delivered the expected emissions reductions. Others have also comprehensively rebutted these two myths.[101]

As shown in the table below, there is a very strong relationship between greater use of wind energy and a reduction in the carbon intensity of a country's electric sector, with Europe's wind energy leaders significantly outperforming the average reduction in electric sector emissions intensity for European OECD countries. Germany's carbon emissions would have fallen even further had it not drastically reduced its use of nuclear generation at the same time for unrelated reasons.

Country	2002 wind %	2012 wind %	2002-2012 decrease in electric sector emissions/MWh
Denmark	12.41%	33.42%	41.35%
Portugal	0.79%	22.01%	30.62%
Spain	3.81%	16.63%	30.14%
Ireland	1.54%	14.53%	28.08%
Germany	2.70%	8.05%	12.78%
OECD Europe	1.09%	5.73%	12.49%

Reliably and cost-effectively integrating large amounts of renewable energy will be even easier in the U.S., as American renewable resources are more diverse and produce more energy more consistently. The U.S. power system is larger and more flexible than that in most of Europe, with abundant hydroelectric resources, flexible gas generation, and more weather-driven electricity demand variability that, as explained above, cancels out much of the variability of renewable energy. In contrast, Ireland is essentially an electrical island with minimal transmission ties and an inflexible generation fleet, and Spain and Portugal have similarly succeeded with minimal transmission ties to neighbors.

[101] See, for example, http://blog.rmi.org/blog_2013_07_31_debunking_renewables_disinformation_campaign, http://blog.rmi.org/separating_fact_from_fiction_in_accounts_of_germanys_renewables_revolution

10. What is needed to reliably accommodate higher levels of wind?

Grid operating reforms and transmission upgrades are by far the lowest hanging fruit for making the power system more flexible and efficient. Bulk power system grid operating reforms and transmission upgrades that facilitate the integration of renewable energy also provide major net benefits to consumers and improve reliability even in the absence of wind energy, so they can be implemented at negative cost.

Reports by NREL[102] and the Western Governors Association[103] provide an overview of reforms to grid operations practices that can cost-effectively improve power system flexibility and efficiency, including:

- Better coordinating regional grid operations, such as through RTOs/ISOs or shared markets like an Energy Imbalance Market[104] (EIM)
- Consolidation or better coordination among grid operators
- Faster generation scheduling and dispatch intervals
- Better integrating wind energy forecasting into grid operations
- Establishment of ancillary services markets that incentivize flexible resources such as demand response and flexible generation

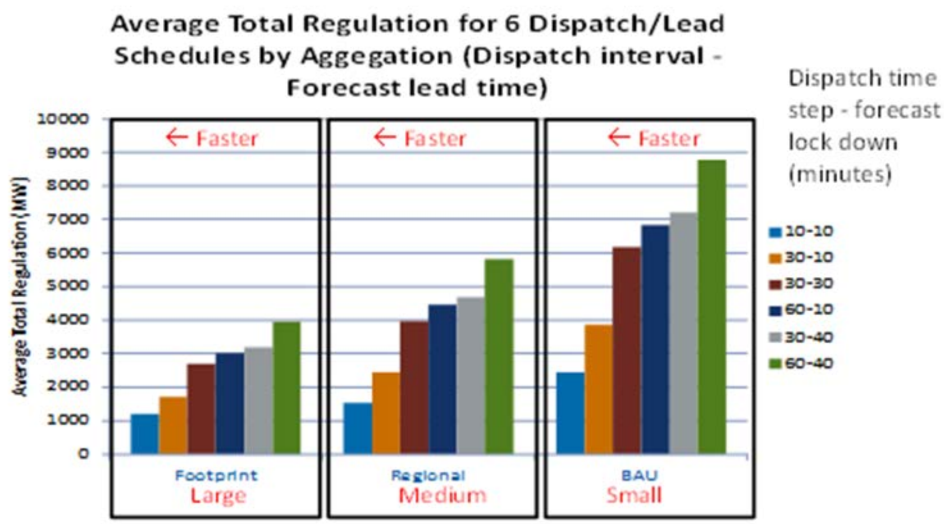
One of the most beneficial solutions is an Energy Imbalance Market, or EIM. An Energy Imbalance Market is a voluntary market that allows utilities and other grid operators to "net out" changes in electricity supply and demand with their neighbors. This is typically much more cost-effective than each individual grid operating managing all variability on its own without regard for what its neighbors are doing.

For example, under current operating practices in much of the Western U.S., one utility may be ramping up its gas power plants to accommodate an unexpected increase in electricity demand, while a neighboring utility is ramping its gas power plants down to accommodate an increase in wind generation. A far more efficient solution would be for the utilities to allow the increasing wind generation to meet the increasing electricity demand and not change the output of their gas power plants. As described above, this diversity benefit is one of the fundamental reasons why large interstate power systems were built in the first place.

An EIM also reduces another major inefficiency in current power system operations in the Western U.S. Currently, most power plants are told to produce at a constant level of output for an hour, which requires the use of expensive operating reserves to accommodate intra-hour changes in electricity supply and demand. In much of the rest of the U.S., grid operators allow generators to change their output levels at intervals of 5 minutes and with lead times of 10 minutes or less, rather than hourly. This allows generators to use their inherent flexibility to respond to changes in electricity supply and demand based on the incentives provided in the energy market. Instead of holding enough expensive operating reserves to handle the worst case of supply and demand variability that could occur over the course of that hour, this variability is accommodated at virtually no cost through the energy market. An additional benefit is that the less than 10 minute lead time for updating generator output levels allows for a far more accurate forecast of electricity demand and supply than is possible an hour or more ahead.

As shown in the chart below, coordinating grid operations over a larger area and allowing faster and more frequent updates to generation dispatch greatly reduces the need for operating reserves.

[102] Available at: http://www.nrel.gov/docs/fy09osti/46273.pdf, http://www.nrel.gov/docs/fy13osti/60451.pdf and http://www.nrel.gov/electricity/transmission/energy_imbalance.html
[103] Available at: http://www.westgov.org/component/docman/doc_download/1610-meeting-renewable-energy-targets-in-the-west-at-least-cost-the-integration-challenge-full-report?Itemid=
[104] http://www.caiso.com/Documents/EnergyImbalanceMarket_FrequentlyAskedQuestions.pdf



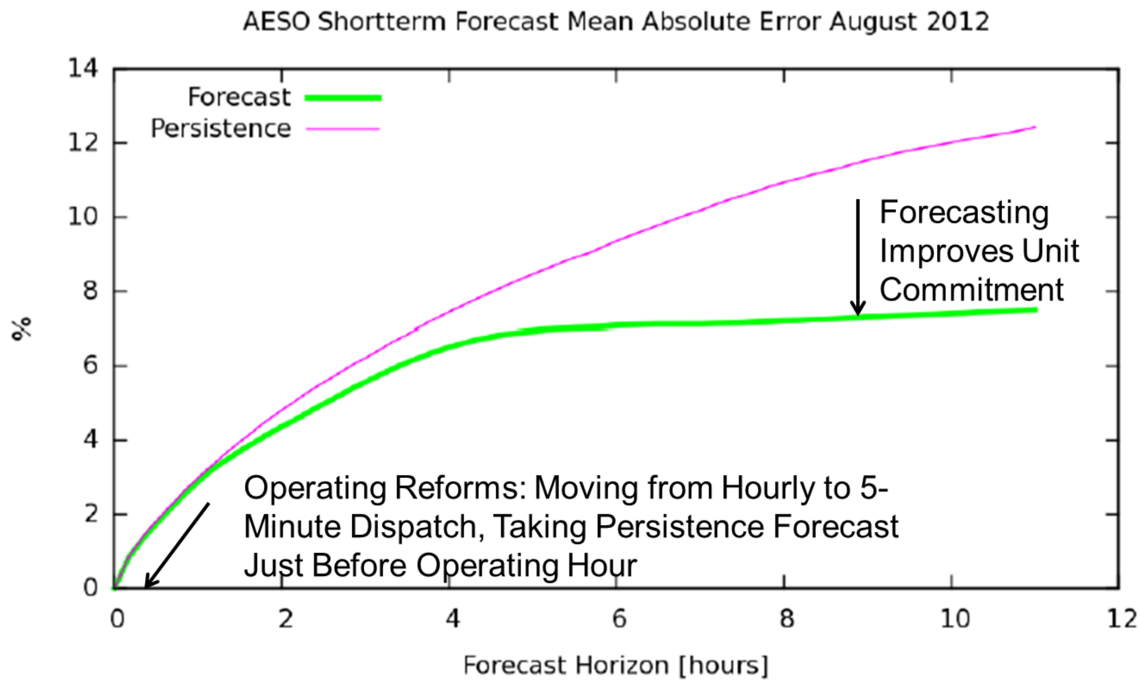
Milligan, Kirby, King, Beuning (2011), The Impact of Alternative Dispatch Intervals on Operating Reserve Requirements for Variable Generation. Presented at 10th International Workshop on Large-Scale Integration of Wind (and Solar) Power into Power Systems, Aarhus, Denmark. October

Many studies have documented the sizeable net benefits of grid operating reforms like an EIM. In particular, these studies have examined potential grid operating reforms in the Western U.S., where hourly generator dispatch is still the norm and there has been significant discussion about the opportunity to move to an EIM.[105] The EIM model is based on the successful use of an EIM in the Southwest Power Pool region.[106] The California grid operator and the large interstate utility PacifiCorp launched an EIM in the fall of 2014, which has already produced an estimated $6 million in benefits during its first two months of operation.[107]

Grid operating reforms like an EIM are by far the lowest hanging fruit for making the power system more flexible, and in fact they can be done at a negative cost to consumers. NREL calculated that an EIM would provide annual benefits of $1.312 billion from faster dispatch and additional regional coordination benefits of $146 million from a region-wide EIM.[108]

Reducing the generation dispatch interval from one hour to 10 minutes and setting generation schedules at 10 minutes or less before the operating hour, both of which are accomplished under an EIM, are the single most important steps for improving the efficiency of power system operations and facilitating the integration of renewable energy. Setting schedules as close to real-time as possible greatly reduces the cost and reserve need for integrating wind energy because wind energy forecast error falls drastically as one gets closer to real-time, as shown in the chart below.[109]

[105] See http://westernenergyboard.org/energy-imbalance-market/documents/, http://www.westgov.org/PUCeim/documents/07-12-13EIMgu.pdf
[106] http://www.spp.org/publications/spp_market_launch_feb_01_2007.pdf
[107] http://www.caiso.com/Documents/PacifiCorp_ISO_EIMBenefitsReportQ4_2014.pdf
[108] http://www.nrel.gov/docs/fy13osti/57115.pdf, page xviii
[109] http://www.nrel.gov/docs/fy14osti/61035.pdf, page 4, with text and arrows added by AWEA



The benefits or these reforms are not limited to reducing consumer cost and facilitating the integration of renewable energy by allowing more efficient operations, but also improving electric reliability through greater grid operator situational awareness and increased opportunity for sharing operating reserves. A FERC staff white paper[110] provided qualitative assessment of these reliability benefits. Recent work[111] by Synapse Energy Economics quantified the reliability benefits of an EIM. By assuming that the 2011 Southwest outage might have been prevented from spreading due to the real-time grid awareness provided by a well-designed and well-functioning EIM, Synapse Energy Economics calculated the potential reliability value of in EIM in that case at $775 million.

AWEA has compared study results on the costs and benefits of grid operating reforms like an EIM, versus the costs and benefits of other flexibility solutions. The results are presented in the chart and table below, in an attempt to quantify where these options would fall on the "flexibility supply curve" for the Western U.S. The lowest cost options appear below the x-axis as they have a negative cost, while higher cost options appear above the x-axis. As is the case with any supply curve, the most cost-effective mix of resources is chosen by beginning at the bottom left of the supply curve and moving up the supply curve until the need has been met. Based on the flexibility needs identified in NREL's Western Wind and Solar Integration Study, the flexibility provided by the grid operating reforms encompassed in an EIM would be more than enough to accommodate a very high level of renewable use at negative cost.

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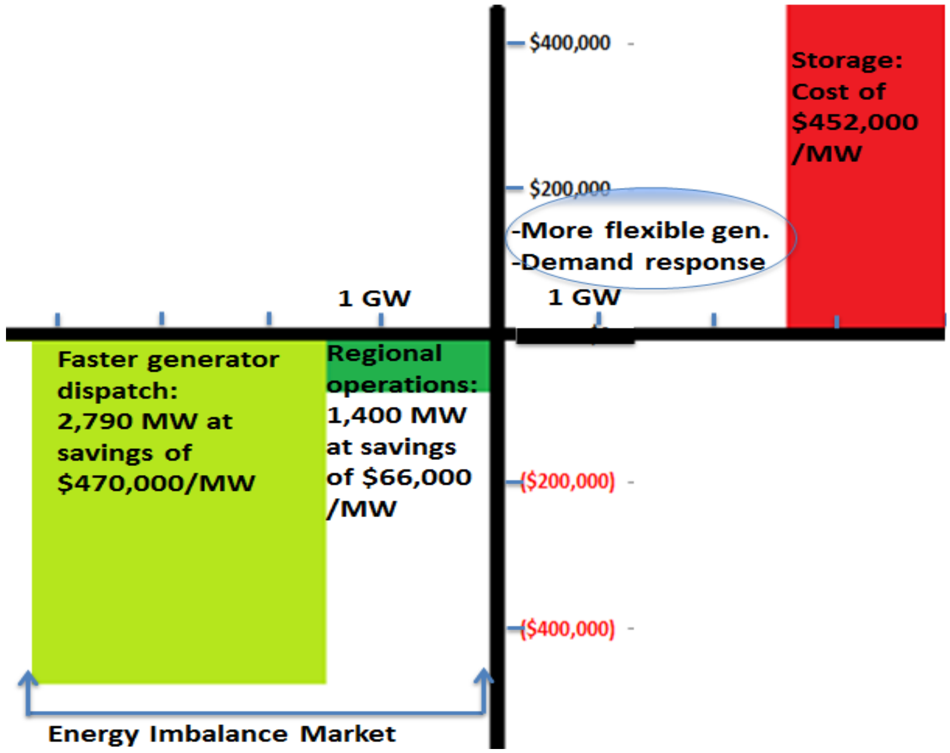
[110] FERC Staff, Qualitative Assessment of Potential Reliability Benefits from a Western Energy Imbalance Market, February 26, 2013, available at: http://www.westgov.org/PUCeim/meetings/2013sprg/briefing/03-08-13FERC-EIMrbqa.pdf.

[111] "Balancing Market Opportunities in the West: How participation in an expanded balancing market could save customers hundreds of millions of dollars." Prepared for the Western Grid Group October 10, 2014. Paul Peterson, Spencer Fields, Melissa Whited. Posted on the Western Grid Group website at: http://www.westerngrid.net/wp-content/uploads/2014/10/EIM-Synapse.pdf



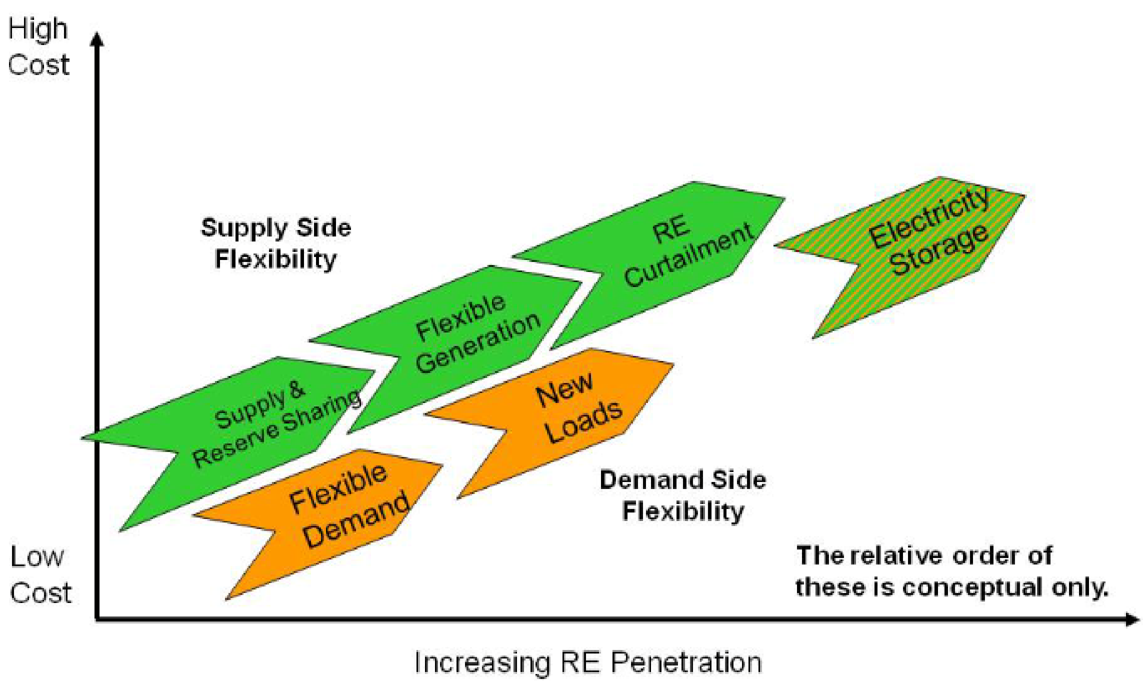
	Faster dispatch	Regional coordination	Storage
Benefit/year ($M)	$1,312	$146[112]	$0.05[113]
Cost/year ($M)	$54.16[114]		$0.50[115]
Benefit/Cost ratio	27		0.1
MW of flexibility provided	2790	1397[116]	Variable
Annual cost per MW of flexibility	($470,250.90)	($65,740.16)	$452,000.00

These results show that grid operating reforms are by far the lowest hanging fruit for improving power system flexibility, particularly the fast generator dispatch and regional grid coordination provided by an

[112] Annual benefits of $1.312 billion from faster dispatch and additional regional coordination benefits of $146 million from region-wide EIM, http://www.nrel.gov/docs/fy13osti/57115.pdf, page xviii
[113] $50/kW-year increase in the economic value of pumped hydro storage at 30% wind, http://emp.lbl.gov/sites/all/files/lbnl-6590e.pdf, page 44
[114] This is the estimated annualized cost of an EIM, which would encompass both faster generator dispatch and regional coordination on grid operations. The annualized cost was calculated by taking the sum of SPP's estimated start up first year cost for the EIM operator and the average of NWPP's low and high estimates of EIM participant startup costs for all BAs in the West, and annualizing them. That number was added to ongoing costs, which were derived from SPP's ongoing EIM operator cost estimate plus the average of NWPP's low and high estimates of EIM participant ongoing costs. Sources include http://www.nwpp.org/user_documents/040313_EIM_Preliminary_Quantitative_Results.pdf, http://www.westgov.org/PUCeim/meetings/2013sprg/briefing/present/m_milligan.pdf, http://www.westgov.org/PUCeim/documents/07-12-13EIMgu.pdf, http://www.westgov.org/PUCeim/documents/03-15-13WECCrcp.pdf
[115] Annualized capital cost of $700/kW-year for pumped hydro, minus $198/kW-year benefit to the power system in the absence of renewable energy. http://emp.lbl.gov/sites/all/files/lbnl-6590e.pdf, page 44
[116] Average reduction in flex reserve needs from fast dispatch and regional coordination from http://www.nrel.gov/docs/fy13osti/57115.pdf, page 46

Energy Imbalance Market. These two reforms encompassed in an EIM reduce power system costs by hundreds of millions of dollars by improving power system efficiency, repaying for the cost of implementing these reforms many times over. In contrast, energy storage is a far more costly option for power system flexibility. Data was also gathered on the costs and benefits of demand response and more flexible generation (both new generation as well as making existing generation more flexible), which indicated that the net cost per MW of this type flexibility placed it somewhere between $0 and the cost of storage.

The concept of a "flexibility supply curve" has been frequently discussed by NREL and other wind integration experts. For example, the following chart is a conceptual effort to list and roughly rank some of the grid resources that are available to provide flexibility, in order of increasing cost.[117] Its results are consistent with the findings presented above, namely that supply and reserve sharing is one of the lowest cost options for providing flexibility, far lower than the cost of energy storage. Grid operating reforms that achieve greater utilization of existing flexibility while more than paying for themselves by improving power system efficiency should be the first priority in any effort to make the power system more flexible.



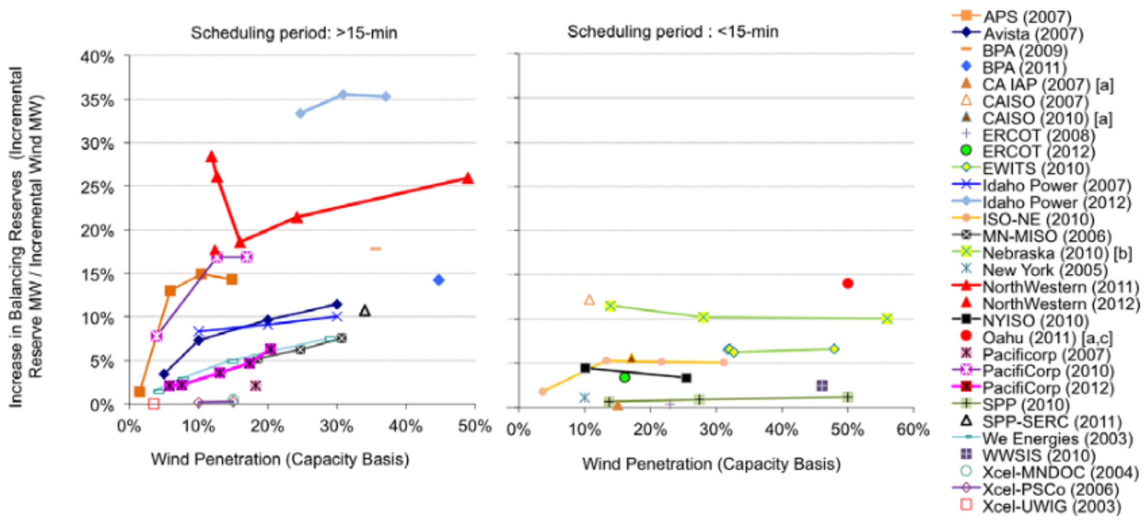
5-minute generation dispatch intervals and setting generation schedules at 10 minutes or less before the operating hour are now standard practice in most of the country. Hourly generation schedules and long lead times for setting generation schedules are a relic of an era before computers and modern communications equipment when generation schedule changes had to be communicated by telephone. By removing barriers to using existing flexibility on the power system and spare transmission capacity that is underutilized in the vast majority of hours, reforms like an EIM can greatly increase power system flexibility and efficiency at very low cost.

Concerns about the reliable and cost-effective integration of wind energy are now almost exclusively relegated to the parts of the Western U.S. that continue to use outdated grid operating practices. As

117 http://www.nrel.gov/docs/fy10osti/47187.pdf

described above, grid operators that use efficient practices, such as MISO and ERCOT, have found wind's impact on operating reserve needs and costs to be trivially small, even with more than 10,000 MW of operating wind generation.

The following chart from the DOE/Lawrence Berkeley National Laboratory Annual Wind Technologies Market Report also illustrates the value of efficient grid operating practices for greatly reducing the incremental operating reserve need and cost associated with integrating wind energy. Regions with efficient grid operating practices see much smaller integration costs, as shown in the chart below illustrating that regions with fast sub-hourly scheduling (on the right) have much lower wind-related operating reserve needs than regions with hourly scheduling.[118]



Grid operating reforms to create more coordinated and efficient generator dispatch across the Western U.S. provide more than enough flexibility to accommodate very high penetrations of renewable energy at a negative cost by drastically reducing operating reserve needs.[119] Given the demonstrated ability of regions with efficient operating practices to integrate large quantities of renewable energy, any obstacles or major cost associated with increased renewable energy integration are entirely due to inefficient grid operating practices that need to be updated anyway.

[118] https://www1.eere.energy.gov/wind/pdfs/2012_wind_technologies_market_report.pdf, page 64
[119] http://www.nrel.gov/docs/fy13osti/60451.pdf

11. Isn't energy storage necessary to integrate wind?

No. Some of the most common questions about wind power involve the role of energy storage in integrating wind power with the electric grid. It is important to understand that very large amounts of wind energy can be reliably integrated at low cost without a need for energy storage, and that energy storage provides a variety of services and is therefore best viewed as a power system resource and not a resource for wind energy or any other individual resource. Moreover, as explained by the flexibility supply curve discussed Question 10 above, energy storage is typically a more expensive source of flexibility than grid operating reforms that allow greater use of the flexibility that already exists on the power system today.

The reality is that, while several small-scale energy storage demonstration projects have been conducted, the U.S. has been able to add more than 65,000 MW of wind power to the grid without adding any large-scale energy storage. Similarly, European countries like Denmark, Spain, Ireland, and Germany have successfully integrated very large amounts of wind energy without having to install new energy storage resources. In the U.S., numerous peer-reviewed studies have concluded that wind energy can provide 30% or more of our electricity without any need for energy storage.

The key to doing so lies in using the sources of flexibility that are already present on the electric grid. As discussed earlier, grid operators constantly accommodate variability in electricity demand and supply by increasing and decreasing the output of flexible generators and other sources of flexibility. A tremendous amount of flexibility has been built into the power system to accommodate large and abrupt swings in electricity supply and demand. Because these power plants and other sources of flexibility have already been built, it is almost always much cheaper to use this flexibility than to build new sources of flexibility like energy storage facilities.

While continuing advances in energy storage technology can make it more economically competitive as a source of grid flexibility, and improving the performance and reducing the cost of battery storage remains critical for enabling greater electrification of the transportation sector, it is important to remember that resources like wind energy can already be cost-effectively and reliably integrated with the electric grid without energy storage.

The high cost of energy storage relative to other sources of flexibility, including those on the existing power system, is the chief reason why it is not more widely used today. In addition, many types of energy storage are poorly suited to help accommodate the specific type of variability that wind energy adds to the electric grid. As explained in the answer to Question 2 above, wind energy output shows very little variability over the minute-to-minute timeframe, with significant changes in output only tending to occur over time periods of 30 minutes or more. Fortunately, it is much cheaper to provide flexibility over these longer time periods using existing resources; as illustrated in the ERCOT data provided earlier, slower-acting reserves can be obtained at a fraction of the cost of faster-acting reserves. Some energy storage technologies, such as flywheels and advanced batteries, can be cost-effective for accommodating demand variability on the second-to-second time frame, but such technologies provide little to no value for wind integration.[120]

There are also fundamental limits to most energy storage technologies for providing the services needed at very high penetrations of wind energy, such as those in excess of 50% annual penetration by energy. As illustrated below, no energy storage technologies in current widespread use are of sufficient scale to move dozens or even hundreds of GWh of energy hours or even days in time.[121] Pumped hydroelectric storage,

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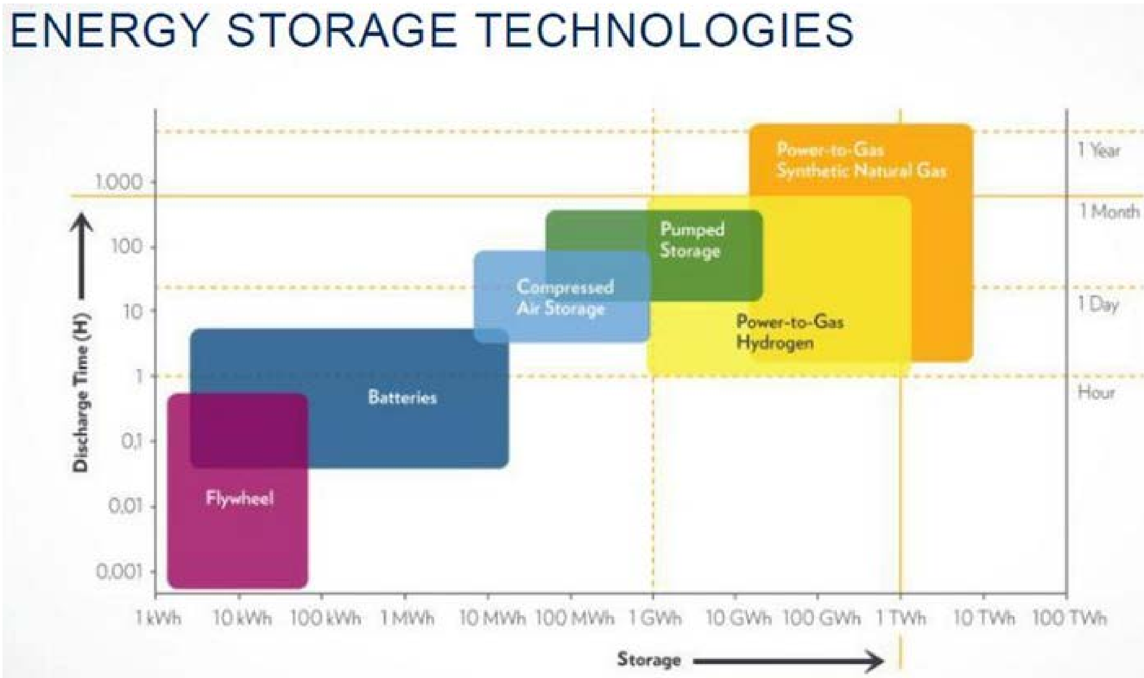
[120] See, for example, http://emp.lbl.gov/sites/all/files/lbnl-6590e.pdf
[121] http://www.itm-power.com/energy-storage/power-to-gas-energy-storage-solution/

with its ability to store large amounts of energy for long durations, is the only energy storage technology that is currently available that comes close to providing this type of service.



As discussed in the answer to Question 5, some people incorrectly assume that wind output must be "firmed," i.e. have its variability leveled out, by storage or another resource to make it valuable to electric utilities or system operators. In reality, there is no need for individual power plants to provide constant power output; this is a good thing, as all power plants experience unexpected outages fairly frequently. As previously discussed, significant variability is already present on the electric grid due to changes in electricity demand and supply as consumers turn appliances on and off and power plants unexpectedly go out of service. Many changes in wind output actually cancel out opposite changes in electricity demand or supply. Therefore, attempting to "firm" wind can actually add to the total variability on the electric grid. Instead, it makes more sense for energy storage to be viewed as a system resource that can help even out the aggregate variability of all generators and all demand on the electric grid, and not used as a dedicated resource for a single generator or load. As a result, a wind plant is seldom the optimal location for deploying energy storage.

In certain rare situations, it could make sense to site energy storage near a wind plant. If a constraint on the transmission grid prevents a wind plant or group of wind plants from selling their full output on a consistent basis, it could be economical to store electricity that would otherwise have been curtailed. However, this type of application is a short-term fix; building out the transmission grid is typically the more optimal long-term solution to a transmission constraint.

In addition, it is important to keep in mind that while energy storage can be an economically attractive option in certain niche applications, such as small island power systems, this does not indicate that energy storage is an economic option on large mainland power systems. Small island power systems, due to geography and fuel mix, often lack low-cost sources of flexibility such as an ability to exchange power with neighboring grid operators. In contrast, mainland U.S. power systems can far more cost-effectively manage variability from all sources by using transmission to exchange power with a neighboring power system.

While energy storage is not needed to integrate wind energy with the electric grid and is often not cost-effective, in some cases having certain types of energy storage on the grid can modestly reduce the cost of integrating wind. However, in some other cases, energy storage has been found to provide negative value for the integration of wind energy, even if the energy storage was provided at no cost.[122] Regardless, given the low cost of using existing flexibility to integrate wind energy, and grid operating reforms that enable far greater use of existing flexibility at negative cost, energy storage technologies should not be viewed as an essential tool for the integration of renewable energy.

The only form of energy storage that is currently operational on a large scale in the U.S. is pumped hydroelectric storage, with a little over 20 GW of installed capacity. In an illustration of that fact that storage is best viewed as a system resource, much of this storage was built to provide flexibility to help accommodate the significant increase in nuclear generation that occurred during the 1960's, 70's, and 80's. Just as it is typically not economic for wind plants to increase their output in response to grid demands, all U.S. nuclear plants and many coal plants tend to provide little to no flexibility.

Thus, all inflexible generators benefit when other sources of flexibility, including energy storage, can relieve them of having to accommodate changes in electricity supply and demand. In fact, studies in the Netherlands[123] and Ireland[124] found that coal plants were the primary beneficiaries of energy storage. Energy storage allowed coal power plants to run more at night, with this low-cost energy being stored and used to displace more expensive natural gas generation during the day, interestingly causing a net increase in electric sector carbon dioxide emissions. In the U.S., DOE data show that pumped hydro storage use declined drastically in 2012 when abnormally low gas prices created an incentive for coal plants to begin cycling their output, reducing the need for storage to provide the flexibility that it had previously been uneconomic for coal plants to provide.[125]

While energy storage technologies may currently have difficulty competing economically with conventional sources of flexibility – especially for accommodating the more gradual variability most relevant for wind integration – continuing advances in energy storage technology can make energy storage more competitive as a provider of grid flexibility. For example, there is significant potential for the batteries of plug-in vehicles to be used as energy storage for the grid, particularly by simply altering the rate of charging of these batteries and therefore avoiding any cycling-related impacts to battery life, because the expense of those batteries would largely be covered by the fuel savings they provide to the vehicle owner. While the potential of such technologies is exciting, it is important to remember that resources like wind energy can already be cost-effectively and reliably integrated with the electric grid without energy storage.

[122] http://emp.lbl.gov/sites/all/files/lbnl-6590e.pdf
[123] http://ieeexplore.ieee.org/xpl/login.jsp?tp=&arnumber=4463799&url=http%3A%2F%2Fieeexplore.ieee.org%2Fxpls%2Fabs_all.jsp%3Farnumber%3D4463799
[124] http://econpapers.repec.org/article/eeeenepol/v_3a39_3ay_3a2011_3ai_3a4_3ap_3a1965-1974.htm
[125] http://www.eia.gov/electricity/monthly/epm_table_grapher.cfm?t=epmt_1_01

12. Why is some wind power curtailed? How does time of production affect the value of wind energy?

In some areas the growth of wind energy has outpaced the addition of transmission. At times this has required reducing the output of wind plants during certain hours until new transmission is added. However, as long-needed grid upgrades are completed, wind curtailment is being virtually eliminated, as are occurrences of negative electricity prices. Regardless of when it is produced, wind energy always has high economic value, particularly once the environmental and public health costs of fossil fuel generation are taken into account.

The majority of curtailment in the U.S. is caused by wind deployment outpacing the development of transmission.[126] When the output of any power plant exceeds the capacity of a transmission line to carry that power to customers, the output of that power plant must be reduced. Wind plants are able to quickly and accurately reduce their output when directed to do so by the grid operator or a market signal.

Some have incorrectly claimed that this curtailment is occurring because of the variability, or other attributes, of wind energy. In reality, any power plant located behind a transmission constraint and facing the same situation would have had its output curtailed.

Transmission upgrades are greatly reducing the transmission congestion that has forced the curtailment of some wind generation in some areas. As detailed in the table below,[127] curtailment of wind generation has been trending down nationally, most notably in ERCOT, where curtailment fell from 17.1% of wind generation in 2009 to only 1.2% in 2013. As additional transmission was brought online through the Competitive Renewable Energy Zone (CREZ) process and changes were made to improve the efficiency of ERCOT's operations, curtailment declined.[128]

	2007	2008	2009	2010	2011	2012	2013
Electric Reliability Council of Texas (ERCOT)	109 (1.2%)	1,417 (8.4%)	3,872 (17.1%)	2,067 (7.7%)	2,622 (8.5%)	1,175 (3.8%)	363 (1.2%)
Southwestern Public Service Company (SPS)	N/A	0 (0.0%)	0 (0.0%)	0.9 (0.0%)	0.5 (0.0%)	N/A**	N/A**
Public Service Company of Colorado (PSCo)	N/A	2 (0.1%)	19 (0.6%)	82 (2.2%)	64 (1.4%)	115(e) (2.0%)	112(e) (1.7%)
Northern States Power Company (NSP)	N/A	25 (0.9%)	42 (1.7%)	44 (1.7%)	59 (1.6%)	125 (3.0%)	284 (5.9%)
Midwest Independent System Operator (MISO), less NSP	N/A	N/A	250 (2.0%)	780 (4.2%)	792 (3.4%)	724 (2.5%)	1,470 (4.6%)
Bonneville Power Administration (BPA)	N/A	N/A	N/A	5* (0.1%)	129* (1.4%)	71* (0.7%)	6* (0.1%)
New York Independent System Operator (NYISO)	N/A	N/A	N/A	N/A	N/A	9 (0.3%)	50 (1.4%)
PJM	N/A	N/A	N/A	N/A	N/A	125# (2.0%)#	284 (1.9%)
Total Across These Eight Areas:	**109 (1.2%)**	**1,444 (5.7%)**	**4,183 (9.7%)**	**2,978 (4.9%)**	**3,665 (5.0%)**	**2,345 (2.6%)**	**2,569 (2.5%)**

126 http://www.nrel.gov/docs/fy14osti/60983.pdf
127 Available at: http://emp.lbl.gov/sites/all/files/2013_Wind_Technologies_Market_Report_Final3.pdf
128 For more information, see: http://www.eia.gov/todayinenergy/detail.cfm?id=16831#

However, curtailment remains a concern in other regions. Just as Texas was able to virtually eliminate wind curtailment by building the CREZ transmission lines, MISO's Multi Value Project transmission lines and pending upgrades in other regions will greatly reduce this curtailment.

Transmission is the only long-term and economically viable solution to curtailment. Energy storage, demand response, smart grid, and other commonly proposed solutions are too small and often in the wrong location to meaningfully reduce curtailment, though they can provide other valuable services to the power system. Deploying demand response, energy storage, or other solutions does not help with wind curtailment unless it is located on the same side of a transmission constraint as a wind plant. Because most wind plants are located in remote areas, there are typically few large sources of electricity demand, and therefore opportunities for demand response, located on the same side of a transmission constraint as a wind plant. More importantly, transmission is the only resource of sufficient size to deliver the hundreds if not thousands of MWh of wind generation that are being curtailed.

Transmission congestion can cause electricity prices to temporarily go to zero or even lower, and this is an efficient market signal for the most expensive generators in that area to reduce their output. Some have mistaken this as a sign that wind generation has low value in general, or misinterpreted the localized negative prices as indicating that there is no need for wind generation anywhere on the power system. In reality, these localized negative prices go away when grid upgrades are completed, as the wind energy is then able to reach customers elsewhere on the power system who have always had a demand for that energy. Again, transmission is the solution, as there is always demand for electricity somewhere.

Even when transmission congestion causes negative prices, this does not mean that wind generation has low societal value. For example, let us suppose 7501 MW of wind generation are being produced behind a transmission constraint that only allows 7500 MW of wind output to reach consumers. As the wind production exceeds 7500 MW, the market price on that section of the grid will drop from the price set by the production cost for the system's marginal fossil-fired power plant to zero or even negative. The compensation for all 7500 MW of wind generators would fall to the zero or negative clearing price, even though the 7500 MW of wind generation that continues to pass through the transmission constraint continues to offset 7500 MW of fossil generation and reduce total system production costs by as much as before. Even though the market price dropped drastically to zero, the total societal value of reduced power system production costs remains the same.

Some have also expressed concerns that wind production during off-peak periods has low value. In reality, wind energy has high value regardless of when it is produced because grid operators use wind electricity to displace the output of the most expensive power plant that is currently online, which is almost always the least efficient fossil-fired power plant that is operating. Regardless of when it is produced, a MWh of wind energy displaces a MWh that would have been produced by burning natural gas, coal, or occasionally oil. As a result, substituting zero fuel cost wind energy for high marginal cost fossil fuel energy always directly reduces the fuel cost and emissions of the power system.

While the efficiencies of power plants vary slightly from one generator to another, in most cases these variations do not significantly change the value of the fuel saved by wind energy. This is even more so the case when one incorporates the negative environmental and public health externalities of fossil fuel use into the equation. Without externalities, it may appear that off-peak wind production that offsets lower production cost coal generation has lower value than wind that produces on-peak and offsets natural gas generation, but once coal's far larger environmental and public health costs relative to gas are accounted for, the value of off=peak wind production becomes far higher.

13. How does the renewable energy Production Tax Credit affect electricity markets and reliability?

Wind energy and the renewable Production Tax Credit are compatible with well-functioning electric power markets. The myth that policies to promote wind have a significant impact on other generation was dismissed as a "distraction" by former Federal Energy Regulatory Commission Commissioner Norris, based on the "compelling" evidence AWEA put forward in a March 2014 report.[129] That report explained that wind's impact is market-driven and comparable to that of any low-cost generation, and trivially small compared to other factors. Moreover, the effect of negative pricing on other generation has been virtually eliminated by new transmission, and that will continue to be the case if workable policies to pro-actively plan and pay for transmission are implemented.

[129] http://ferc.gov/media/statements-speeches/norris/2014/05-15-14-norris.asp; AWEA's report and follow-up analysis available at http://www.aweablog.org/blog/post/ferc-commissioner-exelon-attacks-on-ptc-a-distraction

14. What is wind's net impact on emissions?

Wind energy greatly reduces emissions of carbon dioxide and other pollutants. Analysis using an EPA tool demonstrates that wind energy reduced carbon dioxide emissions by 115 million Metric tons in 2013,[130] and those savings continue to grow as more wind energy is installed.[131] Wind energy also greatly reduces emissions of sulfur dioxide, nitrogen oxides, mercury, and other air pollutants, as well as reducing water usage and other environmental impacts of fossil fuel use.

Some have sought, without evidence, to undermine the large environmental benefits of wind energy by propagating the myth that wind's pollution reductions are smaller than expected because of impacts on the efficiency of fossil-fired power plants due to cycling.[132] The reality is that because renewable variability is a small contributor to total power system variability, renewable variability has a small impact on the cycling of conventional generation.

An NREL analysis examined the impact of cycling on wind's emissions savings based on real-world hourly emissions data collected at all power plants in the Western U.S., and the results conclusively show cycling has a "negligible" impact on wind's emissions savings.[133] NREL's study found that with wind and solar providing 33 percent of the electricity on the Western U.S. power system, one MWh of wind energy would save more than 1190 pounds of carbon pollution on average, with those savings reduced by only 0.2 percent, or 2.4 pounds, as a result of increased cycling of fossil-fired power plants.[134] Grid operator analysis in the United Kingdom also concludes that the impact of wind generation on reserve needs is very small, and that variability reduces wind's emissions benefits by less than 1/10th of 1 percent, or 0.1 percent.[135]

The PJM renewable integration study found similar results, with total emissions being reduced at the expected proportional rate as wind generation levels increased.[136] Moreover, total generator cycling costs actually decreased in the high renewable energy case in PJM's analysis.[137] NREL has also confirmed that the addition of any low-cost generation will increase the cycling of other generators.[138]

A related myth is that retaining or building new capacity to provide needed flexibility will mitigate the pollution reduction benefits of wind energy. This claim fails to understand that retaining or building generating capacity has a negligible impact on emissions as emissions are tied to energy, not capacity. Building more natural gas plants or keeping existing fossil-fired power plants around does not significantly impair efforts to reduce emissions, as power plants that are being used to provide capacity and flexibility only run during the small number of hours per year when those services are needed. Moreover, any MWh produced by that plant will directly displace MWh that would have come from another fossil-fired power plant, so there is essentially zero impact on total emissions.

Generating capacity itself causes no fuel use or emissions. Generating capacity, rather than actual dispatched energy, is what is primarily needed for providing operating reserves, particularly the slower-acting reserves that do noticeably increase in need at high renewable penetrations. The act of holding these reserves involves either keeping an operating power plant slightly below its maximum output or

[130] http://awea.files.cms-plus.com/FileDownloads/pdfs/AWEA_Clean_Air_Benefits_WhitePaper%20Final.pdf
[131] http://www.awea.org/MediaCenter/pressrelease.aspx?ItemNumber=7181
[132] For an example of this false claim being prominently made by a group that receives funding from the fossil fuel industry, see http://www.wsj.com/articles/SB10001424052748703792704575366700528078676
[133] http://www.nrel.gov/docs/fy13osti/57874.pdf
[134] Available at http://www.nrel.gov/electricity/transmission/western_wind.html.
[135] http://www.gizmag.com/uk-national-grid-wind-data/28046/
[136] http://www.pjm.com/~/media/committees-groups/task-forces/irtf/postings/pjm-pris-final-project-review.ashx
[137] Page 33 at https://www.pjm.com/~/media/committees-groups/task-forces/irtf/postings/pris-executive-summary.ashx shows total cycling costs are $870 million in the base case and $500 million in the renewable case.
[138] http://www.nrel.gov/docs/fy11osti/51860.pdf

simply having a non-operating but quick-starting power plant sitting idle in case it is needed, neither of which causes a significant increase in fuel use or emissions, as confirmed by NREL's analysis. Even when these reserves are called upon, the quantity of generation and therefore emissions involved is minimal, and regardless this generation directly displaces generation that would have come from another fossil-fired power plant.

A final permutation of this myth is that increased levels of wind will cause generation to shift from more efficient gas combined cycle plants to more flexible but less efficient gas combustion turbines. This claim is refuted by all wind integration studies to date, which have found greatly reduced generation from gas combustion turbines at higher wind penetrations. For example, PJM's renewable integration study[139] shows Simple Cycle Gas Turbine (SCGT) generation significantly decreasing as the use of renewable energy increases. A California renewable integration study[140] shows gas turbine generation declining (moving down the y-axis) as renewable generation increases (moving from the pink and yellow lines to the blue lines). This conclusion was also reached in the recent Minnesota Department of Commerce wind integration study. [141]Finally, the New England Wind Integration Study[142] also shows Gas Turbine (GT) generation declining as wind generation increases.

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[139] http://www.pjm.com/~/media/committees-groups/task-forces/irtf/postings/pjm-pris-final-project-review.ashx, at slide 55

[140] http://variablegen.org/wp-content/uploads/2013/01/CEC-500-2007-081-APB.pdf, page 98

[141] https://www.edockets.state.mn.us/EFiling/edockets/searchDocuments.do?method=showPoup&documentId={D607FB96-F80C-49EE-A719-39C411D5D7C3}&documentTitle=201411-104466-01

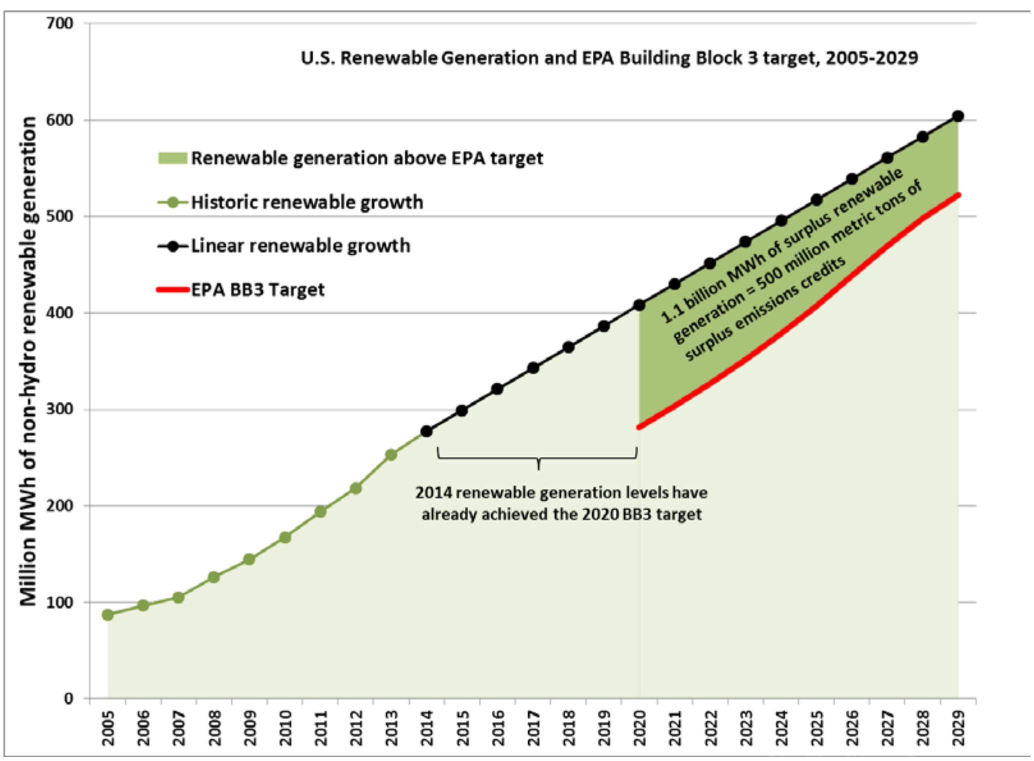
[142] http://variablegen.org/wp-content/uploads/2013/01/newis_report.pdf, at page 213

15. Can wind reliably reach the level of output EPA assumed in its Clean Power Plan?

Yes. Renewable energy has already met EPA's 2020 renewable energy target and is on track to greatly exceed EPA's 2020-2030 renewable energy targets under the Clean Power Plan. By exceeding its targets, wind energy can help states and utilities comply with other parts of EPA's plan, lessening the requirements on other parts of the electric sector.

Under EPA's Clean Power Plan targets, the nation as a whole is targeted to obtain 12% of its electricity from non-hydro renewable sources by 2030, with 17% the highest target for any region.[143] European nations and some U.S. power systems have already demonstrated that much higher levels of renewable energy use can be reliably accommodated.

EPA appears to have underestimated wind energy's recent growth and cost reductions in developing its trajectory for renewable deployment under Building Block 3 (BB3), which contains the renewable energy component, of its Clean Power Plan targets. As shown below, the U.S. has essentially already reached EPA's 2020 target for renewable energy, with 277.4 million MWh of non-hydro renewable energy produced during the last twelve months relative to EPA's target of 281.3 million MWh of non-hydro renewable energy for 2020.[144] Even under the conservative assumption that non-hydro renewable energy continues to expand at the linear growth rate it has experienced over the last 10 years, renewable generation will exceed EPA's BB3 target by 1.1 billion MWh cumulatively over the 2020-2029 compliance timeframe. Because growth compounds as the economics of renewables continue to improve, and because the growth trajectory for 2005-2014 predates much of the cost reduction-driven growth in wind and solar generation, this linear growth projection is likely to be very conservative.



143 http://www.ucsusa.org/sites/default/files/attach/2014/10/Strengthening-the-EPA-Clean-Power-Plan.pdf
144 http://www.eia.gov/electricity/monthly/epm_table_grapher.cfm?t=epmt_1_01_a

Moreover, to the extent states and utilities exceed their Building Block 3 renewable energy targets, they can use the surplus carbon credits to make smaller emissions reductions under the other Building Blocks. Using conservative assumptions, the 1.1 billion MWh of surplus renewable energy credits generated with linear growth over the 2020-2029 period will be worth more than 500 million metric tons of emissions reductions,[145] 1/7 of the cumulative 2020-2029 emissions reductions required under the total Clean Power Plan relative to 2012 emissions levels.[146] This would greatly mitigate any concerns about the ability to reliably and cost-effectively achieve the other EPA Building Blocks.

Wind can also help build a more reliable Clean Power Plan compliance portfolio through a mechanism that may not be readily apparent. Because renewable energy carbon emissions (zero) are lower than gas, a state or utility would have to substitute far more MWh of gas generation to achieve the same level of emissions reductions. Greater use of renewable energy will therefore result in less disruption to the existing generating fleet, potentially reducing cost and reliability concerns about the transition.

Wind energy's lack of fuel price risk also improves its value as a carbon reduction tool. Wind energy provides sustained emissions reductions over the life of the wind project, regardless of the price of other fuels. In contrast, some of the previous emissions reductions that were achieved by dispatching natural gas generators rather than coal generators have subsided as gas prices have risen above the historic lows seen several years ago.[147] This uncertainty makes it more difficult to plan for the quantity of emissions reductions that will be provided, as well as the cost of those emissions reductions.

In the end, it is clear that wind energy is capable of reliably meeting and exceeding EPA's targets. As explained in the answers to the 15 questions above, the levels of wind generation called for under EPA's Clean Power Plan have already been reliably integrated in many grid operating areas, and far higher levels can also be reliably achieved.

[145] Conservatively calculating emissions savings by placing renewable MWh in the denominator of the EPA emissions rate equation and using the generation-weighted average state target of 1,050 lbs/MWh over the 2020-2029 period = 519 million metric tons of carbon reductions attributable to 1.1 billion MWh of renewable generation. If EPA credits renewable generation based on fossil generation displaced, the credited quantity of emissions reductions from 1.1 billion MWh of renewable generation would be significantly higher.
[146] http://www2.epa.gov/carbon-pollution-standards/clean-power-plan-proposed-rule-technical-documents#rate-to-mass
[147] See DOE data summarized at http://www.awea.org/MediaCenter/pressrelease.aspx?ItemNumber=5748