Union of Concerned Scientists

Citizens and Scientists for Environmental Solutions

RENEWABLES:

ENERGY YOU CAN COUNT ON

RAMPING UP RENEWABLES

April 2013

Renewable energy is providing reliable electricity today in the United States and around the world. From 2007 to 2012, electricity from renewable sources such as wind and solar nearly quadrupled nationally. This growth is part of a transition away from dirty, coal-burning power plants—which harm public health and destabilize our climate—toward cleaner, more sustainable sources of electricity. Using existing technologies and smart policy decisions, the United States can continue this clean energy transformation while maintaining a reliable and affordable electricity system.

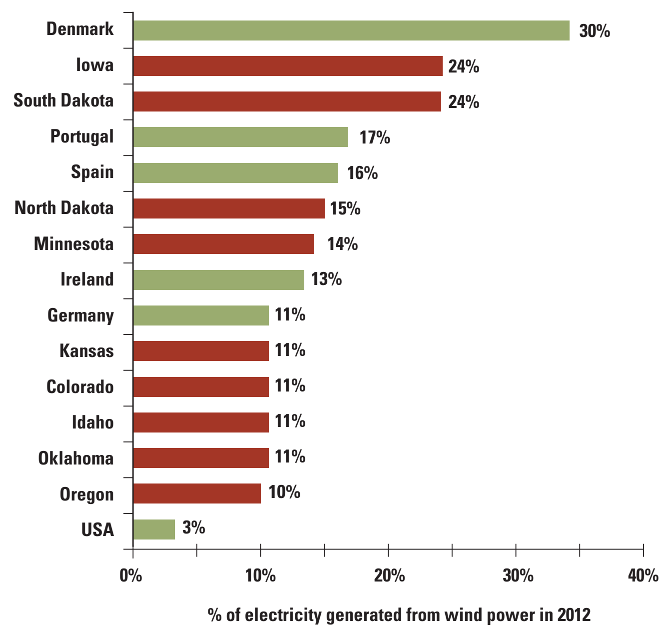
Transitioning to a system that relies heavily on wind and solar facilities—which provide variable amounts of power—does pose challenges to managing the electricity grid. After all, the wind doesn't always blow and the sun doesn't always shine, and grid operators must match electricity demand with supply each and every moment of the day (see Box 1, p. 2). However, meeting electricity demand in the face of variability and uncertainty is not a new concept for grid operators. They already make adjustments for constantly changing demand, planned power plant outages for maintenance, and outages stemming from severe weather, equipment failure, and other unexpected events. Adding variable energy sources to the system may increase the complexity of the challenge, but does not pose insurmountable technical problems or significant costs.

We know this because the U.S. grid and electricity grids throughout the world have already reliably integrated variable energy sources such as wind and solar power. We have the tools to significantly ramp up renewable energy use and keep the lights on. With ingenuity, innovation, and smart policies, we can fully transition to a clean, renewable electricity system.

RECENT GROWTH IN WIND AND SOLAR POWER

A number of utilities, states, and countries already have much higher percentages of renewable energy than many people thought possible just a few years ago (Figure 1). Wind power is growing rapidly in the United States—more than tripling from 2007 to 2012. The nation broke a record in 2012, installing more than 13,000 megawatts (MW) of wind power capacity

Figure 1. Wind power provides a significant share of the electricity generated in many states and countries.



Wind power provided more than 10 percent of the electricity produced in nine states in 2012, with Iowa and South Dakota leading the pack at 24 percent. Denmark is the global leader, with wind power providing nearly one-third of the country's electricity in 2012.

Sources: DEA 2013; EIA 2013; EWEA 2013.

Banner photo: © iStockphoto.com/R-J-Seymour

Box 1. How the Electricity Grid Works

The electricity grid has been called the world's most complex machine. It connects power sources to consumers in homes, offices, factories, and schools through thousands of miles of transmission and distribution wires. Grid operators must exactly match the amount of electricity generated with that required every second of every day, as cities wake up and return to sleep, large factories and home appliances are switched on and off, and generators and transmission lines go into and out of service.

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Grid operators, also called balancing authorities, match electricity demand and the generation and transmission resources within a control area. These operators send a signal to power plant operators to increase or decrease their output as needed. As demand increases, grid operators usually turn plants on—or dispatch them—according to their cost, with the cheapest dispatched first, based on prices the plant owners bid into the power market. When operating or transmission constraints emerge, grid operators may dispatch some plants out of cost-based order, to maintain the reliability of the power grid. The last generator turned on to meet demand at a particular location and time sets the price for the rest of the market.

Grid operators rely on "automatic generation control" (also called frequency regulation) to fine-tune power plant output in response to changes in demand over seconds and minutes. Spinning reserves—plants operating but not running at full power—must be ready to respond within minutes, if needed. Grid operators must maintain enough reserve capacity to meet forecasted peak demand, plus an added percentage to cover unexpected demand or plant outages. They must also maintain a power reserve large enough to replace a sudden loss of the system's biggest source, whether a generating plant or a transmission line.

Large thermal generating stations, such as nuclear and coal power plants, typically operate 80 percent to 90 percent of the time, because they are expensive to build but relatively cheap to run. Operators turn cycling plants—which are usually more costly to run but also more flexible than most coal and nuclear plants—up or down to reflect hourly changes in demand. Operators use peaking plants—with designs that are typically cheap to build but expensive to run—only to meet maximum daily or seasonal demand, such as on hot summer days. Natural gas power plants can be operated as cheaply as coal plants, but they are more often used as cycling and peaking plants, because they can be ramped up and down very quickly.

Some renewable energy technologies—such as hydroelectric, bioenergy, geothermal, landfill gas, and concentrating solar power plants with thermal storage—can be operated just like fossil fuel and nuclear plants. Electricity from variable renewable energy sources such as wind and solar, in contrast, is usually used whenever it is available. However, these sources have very low operating costs because the "fuel"—wind and sunlight—is free.

Energy-saving strategies allow grid operators to manage electricity use and costs by reducing consumption—particularly during high-demand periods, when power is most expensive. Such demand-side measures include efficiency and conservation measures and demand-response programs, which control a customer's demand for power in response to market prices or system conditions.

and investing $25 billion in the U.S. economy (AWEA 2013a). This made wind power the leading source of new capacity in the United States, representing 42 percent of the total, and surpassing new natural gas capacity.

While wind provided only 3.5 percent of the country's electricity in 2012, several states and regions have reached much higher levels. For example:

- In 2012, wind power provided 24 percent of the electricity generated in Iowa and South Dakota, and more than 10 percent in seven other states (EIA 2013).
- On October 23, 2012, the Pacific Northwest set a new record as electricity from wind power exceeded that from hydropower for the first time ever (Sickinger 2012).
- On November 23, 2012, the Midwest set a record when more than 10,000 MW of wind power supplied 25 percent of the region's electricity (Reuters 2012).
- On December 5, 2012, the Southwest Power Pool—which includes Kansas, Oklahoma, and the Texas panhandle—set a record as wind power supplied more than 30 percent of the region's electricity (AWEA 2012b).
- On January 29, 2013, the main grid operator in Texas set a record when wind power produced 32 percent of total supply—enough to power 4.3 million average homes (AWEA 2013b; ERCOT 2013). Texas leads the nation in installed wind power capacity, with more than 12,200 MW at the end of 2012 (AWEA 2013a).

Solar power is also growing rapidly and supplying reliable electricity for U.S. consumers. The capacity of solar photovoltaics (PV) expanded by a factor of five from 2009 to 2012 (SEIA 2013). California leads the nation, with 35 percent of all U.S. PV capacity in 2012. New Jersey, Arizona, Hawaii, New Mexico, and New York have also seen significant investments in solar power during the past few years (Sherwood 2012).

Some of the nation's largest utilities are relying on significant levels of renewable energy. For example, renewables supplied 21 percent of the electricity Southern California Edison (SCE) sold to its 14 million customers in 2011, which included 7.5 percent from wind and solar (Karlstad 2012). SCE was the second-largest retail supplier of solar power in 2011, and the third-largest supplier of wind power (AWEA 2012a; Campbell and Taylor 2012). SCE projects that wind and solar will supply 18 percent of its retail electricity sales by 2017, as the utility works to meet California's renewable electricity standard of 33 percent by 2020 (Karlstad 2012).

Xcel Energy, a Minneapolis-based utility serving customers in eight states, was the largest retail provider of wind power in the United States in 2011, and the fifth-largest solar provider (AWEA 2012a; SEPA 2012). On April 15, 2012—a night when the winds were strong and electricity demand was low—Xcel set a new U.S. record by relying on wind to produce more than 57 percent of its customers' power in Colorado (Laughlin 2012). Xcel is pursuing several approaches to

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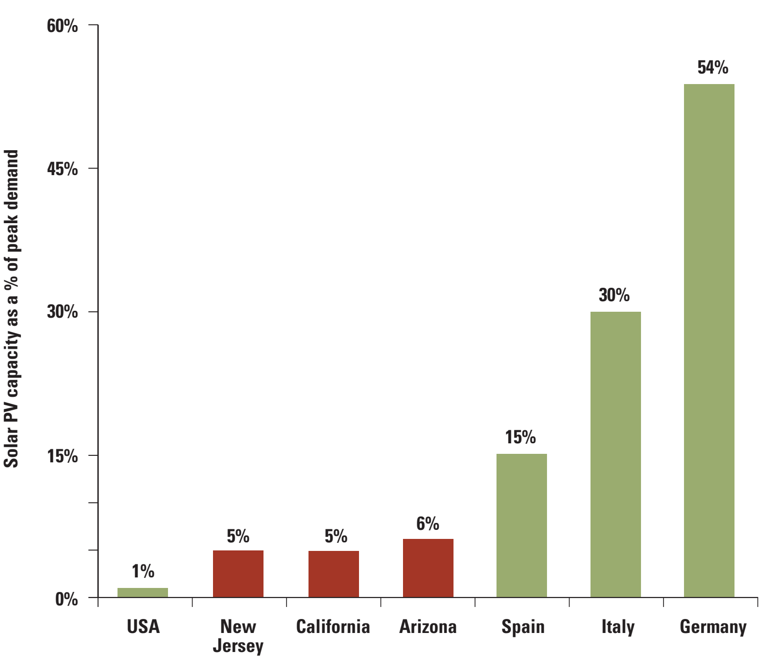
Solar photovoltaic (PV)—installed on homes and businesses and in open spaces—is the fastest-growing energy technology in the world, having expanded by a factor of five from 2009 to 2012. California, New Jersey, and Arizona lead the nation in solar PV capacity. More than 119,000 people work in the U.S. solar industry, which includes 5,600 businesses in every state.

Sources: SEIA 2013; Sherwood 2012; Solar Foundation 2012.

integrating high levels of wind power into its system efficiently and affordably while maintaining reliability (see Box 2).

Globally, renewable energy accounted for almost half of the generating capacity added in 2011, with wind and solar PV accounting for 70 percent of that amount (REN21 2012). In the European Union, renewable sources supplied nearly 20 percent of all electricity consumed in 2010 and more than two-thirds of the total installed capacity in 2012 (EWEA 2013; REN21 2012). Wind supplied 30 percent of electricity in Denmark in 2012 (EWEA 2013). In Germany, renewable energy provided about 25 percent of electricity used in 2012, with more than half coming from wind and solar PV (Figure 2) (Böhme 2012).

Figure 2. Solar power is providing a significant and growing share of electricity in some states and countries.



Germany is the global leader in solar PV, which has the potential to provide more than half of the nation's electricity on hot sunny days, when demand is high and the power is most valuable. In California, which led the United States in installed capacity in 2012, solar PV could provide up to 5 percent of the state's electricity during periods of high demand. New Jersey, Arizona, Hawaii, New Mexico, and New York have also seen significant investments in solar power in the last few years.

Sources: Montgomery 2013; SEIA 2013.

On May 8, 2012, wind and solar reached a record 60 percent of total electricity use in Germany (NREL 2012). On April 19, 2012, wind power set a new record in Spain, generating 61 percent of the nation's electricity (Casey 2012).

REPLACING CONVENTIONAL POWER PLANTS WITH RENEWABLE ENERGY CAN ENHANCE RELIABILITY

While integrating large amounts of variable renewable energy into the grid poses challenges to grid operators, conventional power plants present their own reliability challenges. The potential for a sudden outage at large coal and nuclear plants and transmission facilities means that grid operators must always have generation and transmission reserves on hand to immediately replace them. Because of their size, those facilities also make the grid less flexible and more vulnerable to blackouts when they go offline.

Severe weather events can also affect power plant reliability. For example, freezing temperatures during a cold snap in Texas in February 2011 disabled 152 power plants—mostly coal and natural gas—leading to rolling blackouts across the state (AWEA 2011). Local wind power facilities kept operating and provided enough electricity for hundreds of thousands of homes, reducing the severity of the blackouts. According to Trip Doggett, CEO of the Electric Reliability Council of Texas, "We put out a special word of thanks to the wind community because they did contribute significantly through this timeframe. Wind was blowing, and we had often 3,500 megawatts of wind generation during that morning peak" (Galbraith 2011).

During extremely hot weather, especially droughts, lakes and rivers may be too warm or lack enough water to cool large thermal power plants. For example, in 2007

Box 2. Xcel Energy: The Leading U.S. Retail Provider of Wind Power

Xcel's first big investment in wind power came in 1994, after Minnesota passed a law requiring the utility to increase its reliance on renewable energy in exchange for allowing it to store nuclear waste at its Prairie Island nuclear plant on the Mississippi River. Since that time, state renewable electricity standards (RESs) in Colorado, Minnesota, New Mexico, Wisconsin, and other states have been a key driver of Xcel's investments in wind and other sources of renewable energy.

In Minnesota, Xcel projects that wind and other renewable sources will rise from 13 percent of annual electricity sales in 2011 to 19 percent in 2012, and to 30 percent by 2020, to meet the state's RES. In a compliance report filed with the Minnesota Public Utility Commission (PUC), Xcel reported that energy prices were 0.7 percent lower because it used wind rather than nonrenewable sources. Wind power has also been a major source of income for many farmers, ranchers, and local communities that host wind turbines in Xcel's service territory.

In Colorado, Xcel relied on wind power to provide more than 50 percent of its electricity on several nights when winds were strong and electricity demand was low. On the night of April 15, 2012, Xcel set a U.S. record by generating 57 percent of the electricity it sold in Colorado from wind (Hargreaves 2012; Laughlin 2012). The utility has produced 37 percent of its electricity from wind power in Minnesota under similar conditions.

Xcel has taken several steps to integrate wind into its system while lowering costs. For example:

- Xcel worked with scientists at the National Center for Atmospheric Research in Boulder, CO, to develop a high-resolution wind forecasting system that combines real-time information on wind turbines with weather prediction models to forecast the amount of wind energy that will be available 72 hours in advance (Xcel 2013). Building on decades of atmospheric research, the system is 35 percent more accurate than previous forecasting tools. It has also saved ratepayers more than $14 million by allowing Xcel to reduce output from coal and natural gas power plants, and to cut wind curtailments in half.
- Xcel is also requiring new wind projects to provide regulation service—an operating reserve that tracks changes in supply and demand on a minute-to-minute basis. Xcel had 1,375 MW of wind energy that could provide such service in 2011, allowing grid operators to rely on wind as a more predictable and reliable energy source (Noailles 2012; Schwartz et al. 2012).
- The Midwest ISO and the Minnesota PUC approved a new $730 million, 230-mile, high-voltage transmission line from Brookings, SD, to Minneapolis and St. Paul to support up to 1,000 MW of wind power (Wiser and Bolinger 2011). Other transmission lines approved in the region would support another 4,000 MW of wind power (AWEA 2012a).
- Xcel is purchasing electricity from a two-megawatt solar photovoltaic project near Slayton, MN, in the heart of wind country. The utility is testing whether the project and several wind farms in the area can complement each other and produce more reliable electricity (Xcel 2012).
- In 2008, the utility began testing a one-megawatt battery technology in Luverne, MN, that stores energy from an 11-MW wind farm and moves it to the electricity grid when needed (Xcel 2012). Xcel also partnered with the University of Minnesota–Morris on a wind-to-hydrogen demonstration project. The hydrogen can either be used to produce electricity during periods of high demand or converted to nitrogen fertilizer for use on local farms (University of Minnesota 2008).

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Xcel Energy's Cedar Creek Wind Farm near Grover, CO, helped the utility generate 57 percent of its electricity from wind one night in spring 2012—a U.S. record.

Source: National Center for Atmospheric Research 2011.

and again in 2010 and 2011, the temperature of the Tennessee River rose above 90°F. That ensured the temperature of water discharged from the Tennessee Valley Authority's Browns Ferry nuclear power station would exceed permitted limits, and forced extended reductions in output from the plant (NRC 2011). These cutbacks compelled the authority to purchase electricity at high prices, and cost ratepayers more than $50 million in higher electricity bills in 2010 (Kenward 2011; Amons 2007; Associated Press 2007).

Extreme weather events are expected to become more frequent and more severe because of climate change, which will further strain our reliance on such conventional generating sources. That means events such as Hurricane Sandy—which caused $70 billion to $80 billion in damage and widespread power outages for 8 million people from Virginia to Maine—will become more common (Lee 2012; Webb 2012). Yet renewable energy facilities in the Northeast appear to have weathered the hurricane much better than their fossil and nuclear counterparts (Wood 2012).

Just as diversifying investments strengthens a financial portfolio, adding new energy sources and technologies to the electricity grid can fortify its portfolio—improving its reliability in the process. Renewable resources are less vulnerable to prolonged interruptions in fuel supplies stemming from weather, transportation problems, safety concerns, terrorist threats, and embargoes. And because renewable energy technologies are more modular than conventional power plants, the impact on the grid is usually insignificant when weather damages individual facilities. Because they do not rely on fuels that are subject to price spikes or long-term price increases, renewables also add price stability for consumers.

While we urgently need to transition to a cleaner, low-carbon energy system to reduce the impact and cost of climate change, this transition could take decades because of the enormous scale of the U.S. energy infrastructure, and the complexity of planning, building, and operating electricity grids. We may need to rely on some existing power plants to ensure a reliable electricity supply in some locations, at least in the near term. However, with enough lead time, we can replace such plants with renewable energy, more efficient technologies in homes and businesses, natural gas plants, transmission upgrades, energy storage, and other cleaner approaches.

MANY TOOLS ARE AVAILABLE TO RAMP UP RENEWABLE ENERGY AND MAINTAIN RELIABILITY

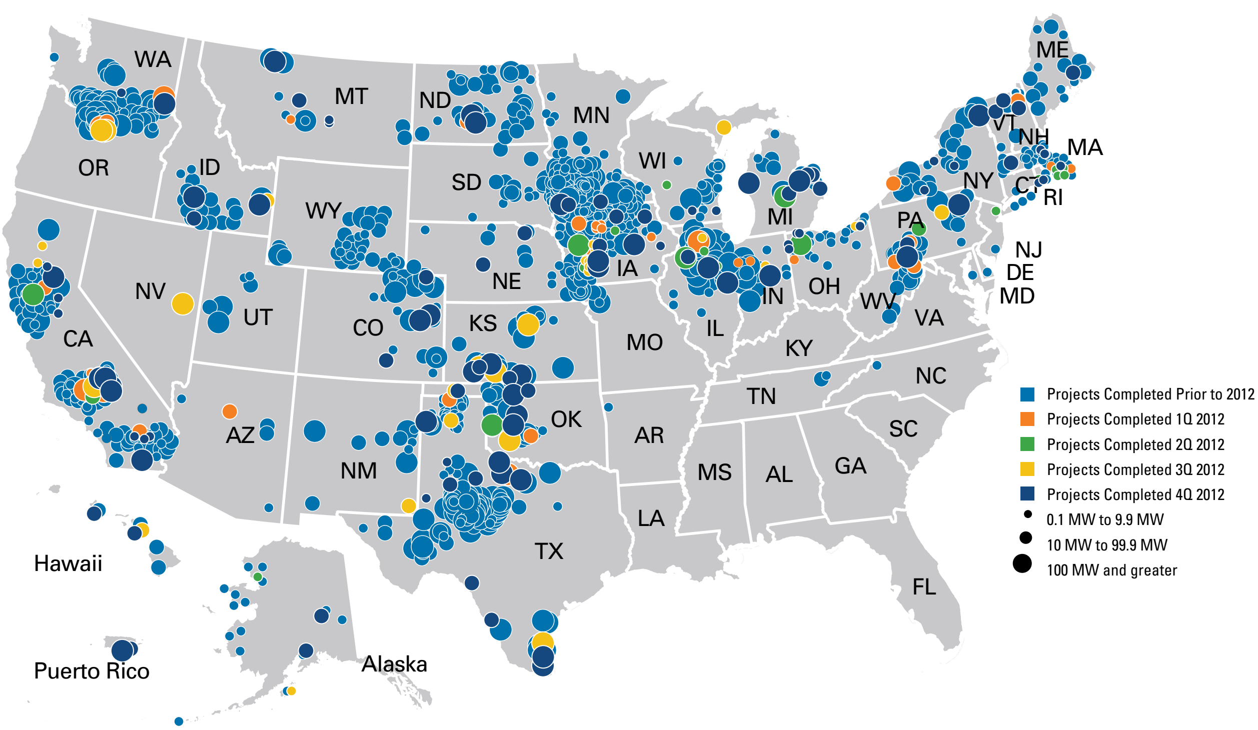
Several new approaches to operating electricity grids can help integrate variable renewable energy resources while lowering costs, reducing emissions, and maintaining reliability. Many of these approaches are being evaluated at the state and regional levels. The Federal Energy Regulatory Commission (FERC) and the North American Electricity Reliability Corporation (NERC) are also changing planning and operating procedures at the national level to remove barriers to integrating renewable energy (Wiser and Bolinger 2011). FERC is an independent federal agency that regulates interstate transmission and wholesale sales of electricity, natural gas, and oil. NERC develops and enforces electricity reliability standards, assesses whether different regions have enough resources to meet demand over a 10-year period, and monitors the bulk power system.

The new approaches that FERC, NERC, regional grid operators, and utilities are implementing include:

Geographic dispersion. In a large interconnected power system, the wind does not blow everywhere, although it is usually blowing somewhere. The amount of sunshine also often varies within a region. Integrating wind and solar projects over larger areas helps smooth out an uneven supply of power from individual projects (Figure 3). Aggregating several wind forecasts and operating data from multiple projects across a larger area improves the accuracy of forecasts. In some regions, wind and solar have complementary availability for meeting electricity demand.

Sharing energy reserves to balance electricity supply and demand over larger areas also greatly reduces the cost and amount of reserves needed to support wind and solar facilities. Combining more than 75 smaller "balancing areas"—regions with authorities designated by FERC to monitor, coordinate, and control the electricity system—in the eastern half of the country into seven larger areas would make attaining 30 percent wind power easier and less costly, according to one study (EnerNex 2010). The problem is even

Figure 3. Wind energy facilities in the United States.



Wind projects throughout the West, Plains, Midwest, and Northeast help smooth out uneven power from individual facilities. Aggregating several wind forecasts and operating data from multiple projects across a larger area improves the accuracy of forecasts. (Where the density of wind projects is high, their location is not precise; to allow the map to show multiple projects, their location is based on counties.)

Source: AWEA 2013a.

> This new forecasting system will enable us to harness wind far more effectively while saving millions of dollars for our customers. We are very pleased to use this as a key tool toward building a diverse portfolio.
>
> —Eric Pierce, Xcel Energy (NCAR 2011)

more acute in the West, which has many very small grid balancing areas that do not coordinate operations with their neighbors (Olsen and Lehr 2012).

Integrating wind and utility-scale solar facilities over larger areas will require investments in more transmission capacity and changes to grid operating procedures, including more coordination between balancing areas. In some regions and states, including the Midwest, New England, mid-Atlantic, New York, and California, FERC has designated an independent system operator (ISO) to control all power plants and transmission lines. In those areas, ISOs can adopt new operating procedures and invest in new transmission capacity to facilitate integration over larger areas. In regions where individual utilities operate plants with little coordination, utilities and states will need to cooperate to integrate wind and solar into the grid.

Better forecasting. All grid operators use forecasting to understand how the weather will affect electricity demand. With growing reliance on wind and solar energy, some larger utilities and regional grid operators are using weather observations, meteorological data, computer models, and statistical analysis to project wind and solar output, and to reduce power and reserves from fossil fuels, cutting costs in the process (see Box 2). Wider use of that approach could save $1 billion to $4 billion annually, according to a study by the National Oceanic and Atmospheric Administration and the U.S. Department of Energy (Haugen 2011).

Improved scheduling. In much of the western United States, operators of wind and solar facilities must schedule power deliveries to the grid on an hourly or day-ahead basis. If actual generation does not match what they have promised, they often face significant cost penalties. When they produce much more power than expected, they are forced to curtail output. Because wind and sunlight can fluctuate over relatively short periods of time, allowing operators to schedule power delivery on a sub-hourly basis can make the grid more efficient, save money, and reduce emissions. Better wind forecasting can also greatly improve the accuracy of such scheduling. FERC has issued new rules that would require grid operators to offer intra-hour scheduling as an option by 2014, and allow operators of variable facilities to provide weather and operating data to improve grid forecasting (Wiser and Bolinger 2011). The implementation of these rules will improve scheduling in the West and between ISOs and their neighbors.

Because these reforms make the grid more efficient, several regions have begun to implement new scheduling rules. For example, the Bonneville Power Administration (BPA) in the Northwest and the California ISO have launched a pilot program that allows wind owners to schedule electricity provided to California every 30 minutes instead of only once per hour. This measure is expected to cut costs, as well as reliance on federal hydroelectric dams now used to balance changes in wind power output over an entire hour. The measure will also reduce the need to curtail wind power when the system does not have enough


© Fresh Energy

hydroelectric power for balancing (Business Wire 2011). According to BPA Administrator Steve Wright, "We can continue to modernize the Northwest grid in new ways that will help lower the costs of wind power while protecting reliability."

All ISOs and regional transmission organizations in the United States already schedule the electricity supply in their regions on a five-minute basis, except the Southwest Power Pool, which will have that approach by 2014. In June 2011, the Midwest ISO required operators of variable renewable facilities to participate fully in the region's real-time (five-minute) energy market. The new approach allows wind to compete with other generators on a more level playing field, reduces the need to curtail renewable facilities, improves system efficiency, and lowers costs and emissions (Paulman 2011; PR Newswire 2011).

Making power plants more flexible. Moving toward more flexible fossil fuel power plants is a relatively easy way to integrate more variable renewable sources into an electricity grid. Most natural gas plants can provide this flexibility, because operators can increase or decrease their output very quickly. Even when natural gas and other fossil fuel facilities provide reserves for short-term balancing, adding wind and solar to a system significantly reduces emissions (Lew 2012; Milligan et al. 2009). Operators of hydroelectric plants can also make a system more flexible by adjusting water flows to match fluctuations in demand and supply.

A large surplus of natural gas capacity exists today because of a surge of new plants built over the past decade. As a result, many natural gas plants are operating well below their design capacity, according to several studies (MIT 2011; Swisher 2011; Kaplan 2010). Replacing less-flexible coal plants with underused natural gas capacity—and adding new gas plants that can start up quickly—could allow operators to integrate renewable energy more easily and cheaply while reducing air pollution and water use. However, a significant increase in the nation's dependence on natural gas has many economic, environmental, public health, and safety risks. Scaling up renewable energy and energy-saving technologies now (see below) is critical to reducing these risks while lowering costs and transitioning rapidly to a low-carbon energy system.

Building new transmission lines. Adding large amounts of renewable energy (or conventional sources) to the electricity system—and delivering high-quality wind and large-scale solar from remote areas to cities—will require new transmission lines. New lines will also be needed to make the grid more reliable, and to integrate wind and solar over larger areas. New lines would make the electricity system more efficient, and enable wind power to displace facilities that cost more to operate.

Some studies have shown that the money saved from operating coal and natural gas plants less often would offset most or all of the costs of adding more transmission capacity (EnerNex 2010). And these studies did not consider making homes and businesses more energy efficient or using small-scale wind and solar, combined heat and power, and other technologies close to where electricity is consumed, which could also reduce costs as well as the need for new transmission lines.

Investment in new transmission capacity—which can take up to a decade to plan, approve, and build—has not kept pace with the rapid growth of wind power in the United States. However, notable progress has been made over the past few years to correct this problem. Transmission projects now being developed could support a near-doubling of wind power capacity over the next eight years (AWEA 2012a). Texas alone is investing $6.5 billion to build 2,300 miles of new high-voltage transmission by 2013 that will support up to 18,500 MW of wind energy (O'Grady 2011).

> We can continue to modernize the Northwest grid in new ways that will help lower the costs of wind power while protecting reliability.
>
> —Steve Wright, Bonneville Power Administration (Business Wire 2011)

In December 2011, the Midwest ISO approved 17 new "multi-value" transmission lines that will support 14,000 MW of wind capacity, help utilities meet state renewable electricity standards, improve system reliability, and provide up to $49 billion in net economic benefits (MISO 2011). Other transmission projects are moving ahead in California and Northwest, Southwest, Mountain, Midwest, and Plains states (AWEA 2012a; Wiser and Bolinger 2012).

Managing customer demand. The least-expensive way to manage variability on the grid is often not to add more power sources but to better manage customer demand. Many utilities already offer "demand-response" programs, which pay large customers to reduce their electricity use when demand is high. For example, ISOs in New England, New York, and the mid-Atlantic region allow demand-response programs to meet future electricity needs if they are less costly than generating the electricity (ISO-NE 2012). These regions use such programs to help balance supply and demand on a minute-by-minute basis, providing more flexibility for integrating wind and solar energy.

Using smart grid technologies. According to analysts at the Massachusetts Institute of Technology, new technologies in sensing, communications, control, and power electronics can make the grid more efficient and reliable, improve the use of existing capacity, and provide greater flexibility in controlling power flows. And those benefits, in turn, would enable operators to integrate large volumes of renewable and distributed power (MIT 2011). For example, the first threshold for allowing more distributed solar on a distribution line is to determine if added supplies exceed demand on that line. By measuring the least amount of power used on a distribution line, instead of only the most, a utility could allow more distributed solar on that line without adding control equipment.

> Our goal is to provide environmentally sound, safe, and reliable energy at a reasonable cost. Adding wind to our portfolio helps us achieve our goals. What's more, adding wind to our energy portfolio has not driven up rates. In fact, it has helped us to continue to reduce costs. Simply put, having a variety of energy options gives us the ability to make the smartest choices for our customers.
>
> —Tim Laughlin, Xcel Energy (Laughlin 2012)

Storage. Several storage technologies are now available to manage variability on the grid over short time frames, as well as to store electricity when demand is low and use it when demand is higher. Many of these technologies have been used for decades to accommodate other sources of variability and uncertainty on the power system, and to help integrate inflexible coal and nuclear power plants. These storage technologies include:

- *Pumped hydroelectric.* These plants store energy by pumping water to a higher elevation when electricity supply exceeds demand, and then allowing that water to run downhill through a turbine to produce electricity when demand exceeds supply. With 22 gigawatts (GW) of installed capacity in the United States—much of it built a generation ago to help accommodate inflexible nuclear power plants—pumped hydro is the largest source of storage in the power system today. However, the potential for more pumped hydroelectric storage is limited, as the long permitting process and high costs make financing new hydro facilities difficult.
- *Thermal storage.* Heat from the sun captured by concentrating solar plants can be stored in water, molten salts, or other fluids, and used to generate electricity for hours after sunset. Several such plants are operating or proposed in

> With new tools and experience, our operators have learned how to harness every megawatt of power they can when the wind is blowing at high levels like this.
>
> — Kent Saathoff, ERCOT (ERCOT 2012)

California, Arizona, and Nevada. The Bonneville Power Administration is also conducting a pilot program in the Northwest to store excess power from wind facilities in residential water heaters (Mason County PUD 2012).

- ***Compressed air energy storage.*** These systems use excess electricity to compress air and store it in underground caverns, like those used to store natural gas. The compressed air is then heated and used to generate electricity in a natural gas combustion turbine. Such facilities have been operating in Alabama and Europe for many years, and developers have proposed several new projects in Texas and California (Copelin 2012; Kessler 2012).
- ***Batteries.*** Batteries can also store renewable electricity, adding flexibility to the grid. AES Corp. is using 1.3 million batteries to store power at a wind project in West Virginia (Wald 2011). Batteries in plug-in electric vehicles can also store wind and solar energy, and then power the vehicles or provide electricity and stability to the grid when the vehicles are idle. A pilot project with the University of Delaware and utilities in the mid-Atlantic region showed that such vehicles could provide significant payoffs to both the grid and owners of electric vehicles, who would be paid for the use of their batteries (Tomic and Kempton 2007).
- ***Hydrogen.*** Excess electricity can also be used to split water molecules to produce hydrogen, which would be stored for later use. The hydrogen can then be used in a fuel cell, engine, or gas turbine to produce electricity without emissions. The National Renewable Energy Laboratory (NREL) has also researched the possibility of storing hydrogen produced from wind power in wind towers, for use in generating electricity when demand is high and the wind is not blowing (Kottenstette and Cottrell 2003).

POWERING THE FUTURE WITH RENEWABLE ENERGY

With these tools in hand, we can ramp up renewable energy to much higher levels. Leading countries and states have set strong targets for renewable energy to realize this future. At least 18 countries have binding renewable electricity standards (REN21 2012). Denmark is aiming to produce 50 percent of its electricity from wind by 2025—and 100 percent of its electricity from renewable energy by 2050. Germany has a binding target to produce at least 35 percent of its

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> Wind represents one of the fuel choices that helps us manage congestion on the system and ultimately helps keep prices low for our customers.
>
> —Joe Gardner, Midwest Independent Transmission System Operator (Reuters 2012)

electricity from renewable sources by 2020—with the target rising to 50 percent by 2030, and 80 percent by 2050. China also has a near-term target of producing 100 GW annually from wind, and is considering doubling its solar target to 40 GW by 2015. These targets are 40 percent higher than installed U.S. wind capacity, and more than five times U.S. solar capacity, as of the end of 2012.

The United States does not have a national target or other long-term policy to expand the use of renewable energy. However, 29 states and the District of Columbia (DC) have adopted renewable electricity standards, which require utilities to supply a growing share of power from renewable sources. DC and 17 states require at least 20 percent renewables by 2025. Hawaii and Maine have the highest renewable standards in percentage terms (40 percent by 2030), followed by California (33 percent by 2020), Colorado (30 percent by 2020), and Minnesota (27.5 percent by 2025) (UCS 2011).

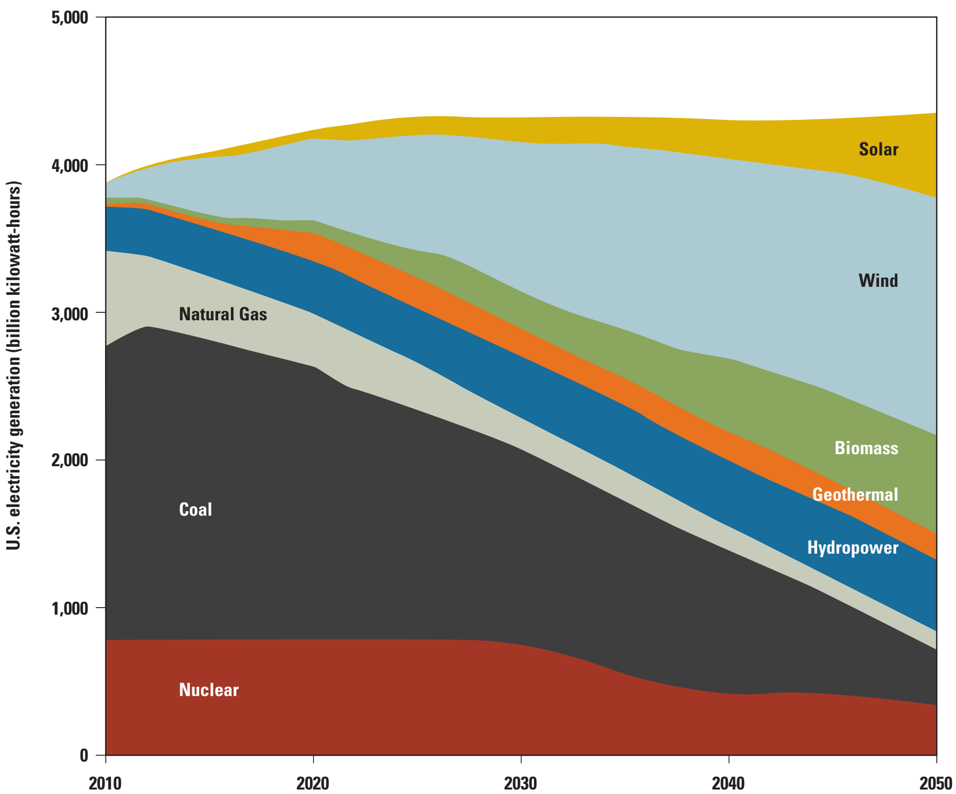
Numerous studies show that we could transition to a low-carbon electricity system based on large shares of renewables within two decades, given the right policies and infrastructure. For example, detailed simulations by U.S. grid operators, utilities, and other experts have found that electricity systems in the eastern and western halves of the country could work by sourcing at least 30 percent of total electricity from wind—and that the West could work with another 5 percent from solar (EnerNex 2010; GE Energy 2010). Using energy storage technologies to balance out fluctuations in these resources would be helpful but not necessary, and not always economical, according to these analysts.

These simulations did show that such gains would require significant investments in new transmission capacity, along with changes in how the grid is operated (as noted above). Expanding transmission lines to allow wind power to supply 20 percent to 30 percent of the electricity used in the eastern United States in 2024 would require just 2 to 5 percent of the system's total costs (EnerNex 2010). However, as noted, reductions in the cost of operating coal and natural gas plants would offset most or all of these new costs.

Other studies have shown that the United States can achieve even higher levels of renewable power while significantly reducing reliance on coal plants and maintaining a reliable, affordable, and much cleaner electricity system. For example, NREL has found that renewable energy technologies available now could supply 80 percent of U.S. electricity in 2050, while meeting demand every hour of the year in every region of the country (Figure 4) (NREL 2012). Under this scenario, wind and solar facilities provide nearly half of U.S. electricity in 2050. NREL also found that an electricity future based on high shares of renewables would deeply cut carbon emissions and water use. Needed investments in new transmission infrastructure would average $6.5 billion per year, according to NREL—within the recent range of such costs for investor-owned utilities.

In *Climate 2030*, the Union of Concerned Scientists analyzed a scenario consistent with targets set by states that are leaders in clean energy investments (Cleetus et al. 2009). The analysis set a national target to cut U.S. carbon emissions 57 percent by 2030, and at least 80 percent by 2050. When combined with improvements in energy efficiency, renewable energy could reliably supply at least half of U.S. electricity needs by 2030, according to this analysis. To achieve these targets, more than half of the renewable power would come from bioenergy, geothermal, hydro, and concentrating solar plants with thermal storage—technologies that can produce electricity around the clock, and during periods of high demand.

Figure 4. Renewable energy could provide 80 percent of U.S. electricity by 2050.



A 2012 study by the National Renewable Energy Laboratory found that renewable energy technologies available today could supply 80 percent of U.S. electricity in 2050, while meeting demand every hour of the year in every region of the country. Under this scenario, wind and solar facilities would provide nearly half of U.S. electricity that year.

Source: NREL 2012.

ACCELERATING THE TRANSITION TO RENEWABLE ENERGY

Achieving high levels of renewable energy will require a major transformation of the U.S. electricity system, as NREL's analysis of attaining 80 percent of electricity from renewables by 2050 suggests:

This transformation, involving every element of the grid, from system planning through operation, would need to ensure adequate planning and operating reserves, increased flexibility of the electric system, and expanded multi-state transmission infrastructure, and would likely rely on the development and adoption of technology advances, new operating procedures, evolved business models, and new market rules (NREL 2012).

Both NREL and MIT's *Future of the Electric Grid* show that a more flexible and smarter grid can overcome challenges to integrating renewables into the grid. However, these changes alone will not be enough to achieve a meaningful transition to renewable electricity. Strong state and national policies are needed to overcome market barriers to developing clean energy and the supporting technologies, and to more fully realize the economic and environmental benefits of transitioning away from coal. Policy support is essential to ensure continued growth of the renewable energy industry, and the cost reductions that come from learning, innovation, and economies of scale.

Expanding on the success of the 29 states with a renewable electricity standard by adopting a strong

Variable power from wind and solar PV would provide 22 percent of total U.S. electricity by 2030.

Another study found that investing in energy efficiency and renewable energy could allow the nation to phase out coal entirely, and significantly reduce reliance on nuclear power (Synapse 2011). A 2011 study by the Intergovernmental Panel on Climate Change concluded that renewable energy could reliably supply up to 77 percent of world energy needs by 2050 (IPCC 2011). And several studies have found that renewables could provide 100 percent of the world's energy needs by 2050 (DeLuchhi and Jacobson 2011; WWF 2011; Jacobson and Delucchi 2010).

national standard of at least 25 percent renewables by 2025 can accelerate the transition to clean energy. Targeted incentives—such as tax credits, direct payments, grants, and low-interest loans—and more funding for research and development are also important for lowering the costs of emerging renewable energy and integration technologies. Strong pollution control standards for coal power plants are also essential to protect public health and the environment.

A national commitment to renewable energy will deliver deep cuts in carbon and other heat-trapping emissions swiftly and efficiently, enabling us to avoid the worst impacts of climate change and help level the playing field between fossil fuels and cleaner, low-carbon energy sources. As *Climate 2030* showed, combining these policies with standards and incentives to invest in more energy-efficient appliances, buildings, and industries can curb energy use, reducing the need to build new power plants and significantly lowering the cost of reducing carbon emissions.

Other low-carbon technologies for producing electricity—such as advanced nuclear plants and fossil fuel plants with carbon capture and storage—may also become available to compete with advanced renewables. If they do, we will have even more opportunities to create a low-carbon energy system. Meanwhile, renewable energy technologies available now—along with investments in energy efficiency and the appropriate use of natural gas—can affordably get us most of the way there.

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