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The Age of Wind

In the global transition from fossil fuels to wind and solar energy, wind has taken the early lead. Wind is abundant, carbon-free, and inexhaustible. It uses no water, no fuel, and little land. It also scales up easily and can be brought online quickly. Little wonder that wind power is expanding so fast.

Over the past decade, world wind power capacity grew more than 20 percent a year, its increase driven by its many attractive features, by public policies supporting its expansion, and by falling costs. By early 2014, global wind generating capacity totaled 318,000 megawatts, enough to power more than 80 million U.S. homes. Wind currently has a big lead on solar PV, which has enough worldwide capacity to power more than 20 million U.S. homes.

The leaders in wind generating capacity are China and the United States. At the start of 2014, China had 91,000 megawatts of wind generating capacity, followed by the United States with 61,000 megawatts. Germany ranked third, with 34,000 megawatts, followed by Spain and India with around 20,000 megawatts each. The

United Kingdom, Italy, France, and Canada were clustered together in the 8,000–10,000 megawatt range.

With some impressive wind power achievements in several countries, it is becoming easier to visualize the new energy economy. In 2013, wind farms generated 34 percent of Denmark's electricity. Portugal's wind share was 25 percent. Spain and Ireland came in at around one fifth each. In fact, Spain's wind farms overtook coal plants as that country's number two electricity source in 2013 and narrowly missed overtaking nuclear power for the lead.

Within Germany, four states in the north are leading the world into the wind century: Mecklenburg-Vorpommern gets 65 percent of its electricity from wind, Schleswig-Holstein gets 53 percent, and Sachsen-Anhalt and Brandenburg each get 51 percent. Each of these states has passed the halfway mark in the transition to the new energy economy.

The year 2013 ended with a bang for wind energy in Europe. In the United Kingdom, strong winds in late November 2013 greatly boosted wind generation and allowed utilities to power down 7,900 megawatts of high-cost gas-fired generators, dramatically cutting their gas expenditures. Wind power met 13 percent of U.K. electricity needs during the week before Christmas. For the year, wind farms generated close to 8 percent of all U.K. electricity.

In December 2013, wind supplied 28 percent of Ireland's electricity. At times during the year, wind was responsible for half of the country's electricity. Denmark, however, won the wind sweepstakes: wind supplied 55 percent of its electricity during December. The next month, Denmark broke its own record, getting an incredible 62 percent of its electricity from wind.

Denmark—a country of fewer than 6 million people that is about one third the size of New York State—

embarked on its path toward such impressive wind generation as a result of the 1970s oil crises. Realizing that being more than 90 percent dependent on oil to satisfy its energy needs was no longer viable, Denmark initially turned to coal and to the prospect of building nuclear power plants. (Anti-nuclear public sentiment led to the abandonment of the latter idea.) The Danish government also used electricity taxes to fund research and development of renewable energy, helping nurture a fledgling wind power industry. The Danish wind company Vestas, which installed its first turbine in 1979, was the leading installer worldwide in 2013.

Wind turbine orders in the early 1980s from California—also spooked by the unpredictability of oil markets—were key in getting Denmark's wind industry going. Now, after nearly 40 years of Danish policies promoting renewable energy—including environmental taxation favoring efficiency and renewables over polluting energy sources—Denmark is well on its way to meeting a goal it set in 2012: getting 50 percent of its electricity from wind by 2020. Energinet.dk, Denmark's state-owned grid operator, reports that the share reached 39 percent in 2014.

Countries are adding wind power to their energy mix for a host of reasons. One of wind's attractions is its small footprint. Although a wind farm can cover many square miles, turbines occupy little land. Coupled with access roads and other permanent features, a wind farm's footprint typically comes to just over 1 percent of the total land area covered by the project.

Wind energy yield per acre is off the charts. For example, a farmer in northern Iowa could plant an acre in corn that would yield enough grain to produce roughly $1,000 worth of fuel-grade ethanol per year, or the farmer could put on that same acre a turbine that generates $300,000 worth of electricity per year. Farmers typically receive

$3,000 to $10,000 per turbine each year in royalties. The Iowa Wind Energy Association estimates that landowners in Iowa already collectively earn more than $12 million a year by hosting wind turbines.

In more densely populated areas, there is often local opposition to wind power—the NIMBY ("not in my backyard") response. But in the vast ranching and farming regions of the United States, wind is immensely popular for economic reasons. For ranchers in the Great Plains, farmers in the Midwest, or dairy farmers in upstate New York, there is a PIMBY—"put it in my backyard"—reaction. Rural communities compete with each other for wind farm investments and the additional tax revenue they bring that can be used to support schools and maintain roads.

Because turbines occupy such a small area of the land covered by a wind farm, ranchers and farmers can, in effect, double-crop their land, simultaneously harvesting electricity while grazing cattle or growing wheat or corn. As wind farms spread across the U.S. Great Plains, wind royalties for many ranchers will exceed their earnings from cattle sales.

In addition to being land-efficient, wind is also abundant. In the United States, three wind-rich states—North Dakota, Kansas, and Texas—have enough harnessable wind energy to collectively satisfy national electricity needs. A 2009 paper in the *Proceedings of the National Academy of Sciences* indicated that at the global level, on-shore wind farms could supply 40 times the electricity the world uses each year, or five times world energy needs. Wind is also not depletable. In contrast with fossil fuels, the amount of wind energy used today has no effect on the amount available tomorrow.

Wind's abundance is matched by its popularity. A January 2014 poll taken in Kansas, for example, showed

that 76 percent of voters strongly support the harnessing of wind energy. And a national poll taken in the fall of 2013 by Navigant Research found that 72 percent of Americans are in favor of wind power. In the European Union, 89 percent of respondents in a 2011 poll were supportive.

Unlike fossil fuel and nuclear power plants, wind farms do not require water for cooling. As wind replaces coal and nuclear plants in power generation, it frees up water for irrigation, residential needs, and environmental purposes. And because it does not emit any airborne pollutants, it reduces the incidence of asthma and lung cancer. In contrast to coal plants, wind farms do not pollute water.

One of wind's strongest attractions is its low cost. With wind there are no fuel bills, so once a wind farm is completed, the only costs are those for operation and maintenance. This is a big reason why wind farm developers can sign long-term electricity supply contracts (power purchase agreements or PPAs) with utilities and private businesses at low fixed rates.

In the midwestern United States, for example, contracts are being signed at a price of 2.5¢ per kilowatt-hour (kWh), which compares with the nationwide average grid price of 10–12¢ per kWh. This price does reflect an important federal tax credit for wind farms, but Stephen Byrd of Morgan Stanley notes that even without the benefit of the tax credit, "some of these wind projects have a lower all-in cost than gas." Further, he says, "in the Midwest it's fairly vicious competition between very efficient wind farms—which are always called on first because they have no variable cost—and coal and nuclear." As the average PPA price for U.S. wind power keeps falling, natural gas, coal, and nuclear power plants will have an even harder time keeping up.

Wind power also has an advantage over conventional sources when it comes to construction time. While it may take a decade or more to build a nuclear power plant, for example, the construction time for the typical wind farm is one year or less.

One of the obvious downsides of wind is its variability. But as wind farms multiply, this becomes less of an issue. Because no two wind farms have identical wind profiles, each one added to a grid reduces variability. A Stanford University research team points out that if thousands of wind farms spread across the United States were connected by a national grid, wind would become a remarkably stable source of electricity.

Another point often raised in opposition to wind power is that birds are killed by the turbines' spinning blades. While bird deaths at wind farms are certainly a concern, improvements have been made over the years in turbine design, with blades turning much more slowly than in earlier models. Avoiding migratory pathways when siting wind farms has also become common practice. In comparison to the old energy economy's power priorities—like coal or nuclear power plants—wind farms cause far fewer avian deaths for each unit of electricity generated. At a broader level, bird deaths from wind farms are but a small fraction of those caused by collisions with buildings, power lines, and automobiles or by house cats.

As the modern wind industry began to take shape in the 1980s, the United States and Denmark dominated the world in wind power capacity. (The former held a healthy lead over the latter.) Then in the 1990s, India and countries in Europe—principally Germany, but also Spain, the United Kingdom, Italy, and France—threw their hats into the ring. By 1997, Germany had wrested the world wind power lead from the United States.

Ten years later, the United States reclaimed the title, but only held it for a few brief years because of what was happening in China. A law was passed there in 2005 to promote renewable energy development, setting the stage for exponential growth in wind power. Each year from 2006 to 2009, China's wind generating capacity doubled, and in 2010 it overtook the United States to become the world wind leader.

In 2013, China's wind farms generated more electricity than its nuclear power plants did. The gap likely widened further in 2014. Wind is now the country's third leading electricity source, behind coal and hydropower. Data from Harvard researchers, writing in the *Proceedings of the National Academy of Sciences*, indicate that China has enough harnessable wind energy to expand its total electricity consumption 10-fold.

In 2008, China's National Energy Administration selected several wind-rich northern provinces to host wind farm mega-complexes, each with at least 10,000 megawatts of generating capacity. These planned "Wind Bases," unprecedented in size, were intended to reach more than 100,000 megawatts of combined capacity by 2020.

The Chinese government, concerned about the underdeveloped electric grid in these remote locations and about project quality suffering with such rapid construction, has since scaled back the Wind Base plans. But even the more modest numbers are impressive. The 3,800-megawatt first phase of Gansu Province's Wind Base in Jiuquan is complete, with another 3,000 megawatts under construction in the second phase. In Hebei Province's Wind Base, some 1,400 megawatts of wind power is now operational, and nearly twice that much is in the construction stage.

Altogether, the Wind Base capacity either finished or under construction in Gansu, Hebei, Inner Mongolia, and Xinjiang Provinces comes to 19,000 megawatts.

With further wind farms planned and under construction, China should have little trouble meeting its official 2020 wind power goal of 200,000 megawatts. For perspective, that would be enough to satisfy the annual electricity needs of Brazil.

Although China has the most installed wind power capacity, the United States produces more electricity from its wind farms than China or any other country does. This is primarily because China's wind farm construction has outpaced transmission and grid upgrades, forcing many turbines in remote regions to sit idle. Additionally, tax incentives for wind projects in China benefit project build-outs, whereas in the United States they reward actual electricity production.

Across the United States, there were 905 utility-scale wind farms in 39 states at the start of 2014, according to the American Wind Energy Association. They provided over 4 percent of the country's electricity generation during 2013, enough to power the equivalent of 15 million American homes.

Texas, California, Iowa, Illinois, and Oregon are the top five states in total installed wind generating capacity. Texas, long the U.S. leader in oil production, now also leads in wind, with 12,400 megawatts of capacity at the start of 2014. In California, the vanguard of wind power development, the capacity figure is 5,800 megawatts. If Texas and California were countries, they would rank in the top dozen wind power nations.

Tri Global Energy, a Dallas-based firm, has leased 640,000 acres in the Texas Panhandle, where it plans to build 16 wind farms. When completed within the next decade, these farms will have 6,600 megawatts of generating capacity, enough to supply 1.9 million U.S. homes with electricity. In all, as of April 2014 the Electric Reliability Council of Texas, which manages most of the Texas

grid, was tracking interconnection requests by wind companies to add 27,000 megawatts of wind power.

In nine states, wind provides at least 12 percent of electricity. Iowa and South Dakota are each generating at least 26 percent of their electricity from wind. If Iowa succeeds in getting half of its electricity from wind farms, which the state wind industry says is possible by 2018 in the right policy environment, it will be the first state in the country to shift from coal to wind as its primary source of electricity.

Warren Buffett's MidAmerican Energy Company brought Iowa closer to that milestone when it announced in December 2013 that it had ordered $1.9 billion worth of wind turbines from Siemens for use in the state. Half were in operation by the end of 2014. The remainder will be online by the end of 2015. In total, the wind farms will add 1,000 megawatts of wind capacity.

More and more, Native American tribes are looking to develop the wind resources on their reservations. At the June 2013 Clinton Global Initiative America meeting, six Sioux tribes announced plans to build one of the largest U.S. wind complexes. Two more tribes have since joined the effort, so the 1,000- to 2,000-megawatt Oceti Sakowin Power Project will now span eight reservations in South Dakota. Revenue from selling the electricity under long-term agreements with outside purchasers will be used for economic development in tribal communities. Project manager Caroline Herron notes that a number of the tribes are also looking to develop their solar and geothermal resources.

Meanwhile, in Oklahoma five tribes are collaborating to build a 153-megawatt wind farm. It will be half-owned by the Cherokee Nation, with the remainder on land belonging to the Kaw Nation, Otoe-Missouria Tribe, Pawnee Nation, and Ponca Nation. Cherokee chief Bill

John Baker said, "The Cherokee Nation expects to play a key role in Oklahoma's emerging wind energy industry."

Also turning to the wind is India, soon to be the world's most populous country. Its 20,000 megawatts of wind generating capacity put it fifth on the world list. New Delhi plans to invest roughly $8 billion in grid transmission upgrades to accommodate much more wind and solar power. Part of this effort is aimed at the 300 million people in India who do not yet have electricity. The National Wind Energy Mission under the Modi government is expected to set an official goal of 60,000 megawatts of wind generating capacity by 2022.

In Latin America, Brazil, with 200 million people, is by far the regional leader in wind resource development. At the start of 2014, it had 3,500 megawatts of wind generating capacity, enough to supply 8 million homes. The goal is to boost capacity nearly fivefold to 17,000 megawatts by 2022. Given its wealth of wind—and the fact that wind developers often win contracts to build new power capacity by bidding below coal or natural gas projects there—Brazil could surpass this goal.

Chile, with a long mountain ridge paralleling its long coastline, is also beginning to harness its abundant wind resources. Its 115-megawatt El Arrayán wind farm, some 250 miles north of Santiago, began generating electricity in June 2014. High electricity prices and a heavy reliance on fuel imports for electricity generation make building up renewable power capacity quite attractive in Chile. As Bloomberg New Energy Finance analyst Ethan Zindler pointed out in a recent interview, "Clean energy is the low-cost option in a lot of [emerging markets]. The technologies are cost-competitive right now. Not in the future, but right now."

After a late start, wind generation is now expanding rapidly in parts of Eastern Europe. Poland, notorious for

its heavy dependence on coal, not only now has 3,400 megawatts of wind power, but the wind segment of the energy economy is growing fast. Romania is close behind with 2,600 megawatts of wind generating capacity.

Bridging Europe and Asia, Turkey has great wind power ambitions, with its long, wind-rich coastline and wind-swept Anatolian plateau. Although it had only 3,000 megawatts of wind generating capacity at the start of 2014, Turkey plans to have 20,000 megawatts within a decade, enough to meet one fourth of its current electricity needs.

Although the harnessing of the earth's wind resources has been limited mostly to resources over land, a growing number of countries are now also tapping winds offshore, where they are often stronger. Denmark built the world's first offshore facility, a 5-megawatt wind farm in the Baltic Sea. At the start of 2014, the country's offshore capacity was close to 1,300 megawatts.

For years, Denmark was the world leader in this field, but in 2007 it ceded this position to the United Kingdom. By January 2014, the United Kingdom had nearly 3,700 megawatts of offshore wind—half the world's total and enough to power more than 2 million homes. The London Array offshore wind farm, with 630 megawatts of generating capacity, is the world's largest offshore wind installation. Other European countries that are beginning to seriously develop their offshore wind resources include Belgium, currently with 570 megawatts, and Germany, with 520 megawatts. The Germans expect to install an additional 2,500 megawatts of offshore capacity by the end of 2015, with a target of 6,500 megawatts by 2020.

In May 2014, a consortium consisting of European companies and Northland Power Inc., a Canadian power producer, announced it was moving ahead with a 600-megawatt wind farm 50 miles off the coast of the Netherlands. This project is part of an effort by the Dutch

to get 14 percent of their energy from renewable sources by 2020.

Close behind the leading European countries is China, with 430 megawatts of offshore wind power installed by early 2014. Although China has come late to offshore wind, as of mid-2014 it had 1,000 megawatts under construction, with another 44 projects totaling 10,000 megawatts in the pipeline. Japan, South Korea, and Viet Nam are among the other countries developing offshore wind resources.

Countries with shallow coastal waters have a distinct advantage in developing large-scale offshore wind resources. These include, for example, countries around the North Sea, the Baltic Sea, and the Gulf of Mexico, as well as the U.S. East Coast.

The U.S. Department of Energy estimates that the shallow waters off the East Coast are capable of hosting 530,000 megawatts of wind generating capacity, enough to satisfy 40 percent of the country's electricity needs. If the wind potential of deeper East Coast waters, as well as the Great Lakes, the Gulf of Mexico, and the Pacific Coast, are included, then offshore wind could easily meet all U.S. electricity needs. About a dozen U.S. offshore wind project proposals are moving ahead, although by late 2014 only two of them had begun early-stage construction: the 470-megawatt Cape Wind project off Massachusetts and Rhode Island's 30-megawatt Block Island wind farm.

In June 2014, U.S. Interior Secretary Sally Jewell and Massachusetts Governor Deval Patrick announced that more than 740,000 acres off the coast of Massachusetts would be designated for offshore wind development and auctioned off as four lease areas. Governor Patrick sees offshore wind as an economic growth opportunity for his state, noting that it has no coal or oil reserves: "We sit at the end of the energy pipeline and we are held in some

sense hostage to the fossil fuel rollercoaster.... Offshore wind…represents an opportunity to create our own Massachusetts-made energy."

This announcement added to the five commercial wind energy leases already granted for areas off the costs of Delaware, Massachusetts, Rhode Island, and Virginia. Then in August 2014 the Department of the Interior awarded two more leases, both offshore of Maryland, totaling nearly 80,000 acres.

Getting the electricity generated by offshore wind farms to population centers presents the challenge of installing the substations, laying the cables, and connecting the turbines at sea. The world's largest offshore wind farms to date have been connected to onshore grids via subsea high-voltage alternating current (HVAC) cables. These include the United Kingdom's 630-megawatt London Array and 500-megawatt Greater Gabbard wind farms, as well as Denmark's 400-megawatt Anholt project. None of these is more than 20 miles off the coast.

Offshore developers in the North and Baltic Seas are now looking farther out for even stronger and steadier wind resources. As the distance from shore grows, so do electricity transmission losses from HVAC cables, which means that at a certain point the much more efficient high-voltage direct current (HVDC) lines are needed. Navigant Research projects that by 2020, HVDC cables will deliver the output from up to 30,000 megawatts of offshore wind farms.

TenneT, the company in charge of transmission systems in the German part of the North Sea, has contracted with firms to develop nine offshore stations that receive the electricity generated by wind farm clusters and then send it via HVDC lines to the German grid. As of mid-2014, Siemens had built four of these hubs and had been awarded a fifth; all told, these will be able to accommodate wind farms with a combined 3,800 megawatts

of capacity. The Switzerland-based power and automation firm ABB was contracted to build three of the other four hubs, good for an additional 2,100 megawatts. The 400-megawatt BARD wind farm, which began generating in 2012, sends electricity roughly 80 miles to shore through one of these ABB stations.

As Germany pursues its *Energiewende*—an "energy transition" from nuclear and fossil fuels to renewables for 80 percent of electricity and 60 percent of total energy by 2050—the offshore wind grid will feed into a cleaner, more efficient grid that is taking shape on land. Along with Germany's three other transmission system operators, TenneT is planning three HVDC transmission corridors running hundreds of miles from windier northern Germany to the country's industrial and more nuclear-reliant south. The western-most corridor, for example, would run 400 miles from the North Sea port town of Emden down to 40 miles northwest of Stuttgart, near the Philippsburg nuclear reactor that is due to close in 2019.

This German grid based on renewable power sources—primarily wind and solar—could eventually be part of a European Supergrid. Envisioned by a coalition of companies—including some of the biggest names in energy, such as Siemens, ABB, General Electric, and Alstom—the Supergrid would be a single-market European high-voltage electricity network delivering power from facilities like Spanish solar farms, Norwegian hydropower dams, and North Sea wind farms to wherever it is needed. It will take much more coordination and commitment among European countries to make this a reality.

Development of long-distance transmission also goes hand-in-hand with wind in the United States, where the strongest onshore wind resources tend to be found in more-remote areas. For example, in the wind-rich but sparsely populated state of Wyoming, a wind farm now

planned by oil billionaire Philip Anschutz will soon be the largest U.S. facility under construction, with 3,000 megawatts of generating capacity. Called the Chokecherry and Sierra Madre Wind Energy Project, this wind farm will tie into one or more of several major transmission lines planned in Wyoming and will supply electricity to high-demand markets in California, Arizona, and Nevada. One candidate for this connection is the planned 725-mile, 3,000-megawatt TransWest Express transmission line—another Anschutz venture.

In Texas, a series of transmission projects linking windy West Texas and the Panhandle with populous areas like Dallas–Fort Worth was completed in early 2014. Some 460 megawatts now under construction in the Panhandle's Mariah wind complex will tie into these new lines. Mariah could eventually reach 6,000 megawatts of capacity or more. Already generating 8 percent of the electricity in Texas, wind farms are now poised to contribute even more to the power supply with these transmission lines in place. Other operational U.S. long-distance transmission lines include the Pacific Intertie, using highly efficient HVDC cables to link wind and hydropower resources in Washington and Oregon with California.

Among the most ambitious players in the U.S. transmission business today is Houston-based Clean Line Energy Partners. The group has proposed building five lines—four of them HVDC—with a combined length of 3,000 miles and the capacity to deliver 15,000 megawatts. For example, the Grain Belt Express Clean Line would link windy western Kansas to Missouri, Illinois, and Indiana. Another will connect the plains of northwest Iowa to Illinois and points eastward.

Perhaps the most exciting grid project under development is the proposed Tres Amigas Superstation electricity hub to be built in Clovis in eastern New Mexico. It will

link the three major power grids of the United States: the Western Interconnection, which includes the West Coast, Arizona, and much of New Mexico; the Eastern Interconnection, which extends from the Atlantic Coast to the Rocky Mountains; and the Texas Interconnection.

This initial linkage of the three grids will allow electricity to move from one part of the United States to another as conditions warrant. It is a landmark in the evolution of the new energy economy. By matching surpluses with deficits over a broader area than previously possible, electricity losses and consumer rates can both be lowered. Intermittent resources like wind and solar can be more easily balanced over a wider geography.

Beyond expanding wind power's reach into new areas, a leading source of growth in the wind energy sector is repowering: the replacement of older wind turbines with larger, more-productive ones. In one replacement project in California, 34 new 2.3-megawatt wind turbines replaced 438 small turbines that dated from the 1980s. Although the total generating capacity stayed roughly the same, the highly efficient new turbines produce more than twice as much electricity. In more-mature markets like California, Germany, Denmark, and Spain, repowering and refurbishing old turbines is supplying more power than brand-new wind farms do.

The impressive growth in world wind electricity generation is likely to continue in the years ahead, with an expanding share of the growth coming in developing countries. As wind technologies continue to advance and costs continue to decline, wind will emerge as a leading source of electricity.

Data, endnotes, and additional resources can be found at Earth Policy Institute, www.earth-policy.org.