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The Solar Revolution

In April 1954, top scientists gathered in Washington, D.C., to hear something new: voice and music broadcast by a solar-powered radio transmitter. Scientists at Bell Labs in New Jersey were demonstrating their invention, the first practical solar cell, which was made of silicon. This breakthrough paved the way for the solar revolution taking place today on rooftops and in massive ground-mounted solar farms around the world.

Solar cells, also called solar photovoltaics or PV, powered U.S. satellites during the 1960s space race with the Soviet Union. But PV technology was still too expensive to be used for much else until the Arab oil embargo of 1973. Amid rising fears about energy security, governments and private firms poured billions of dollars into solar research and development, reaping big gains in efficiency and cost reductions. This led to widespread use of PV in the 1980s for powering telephone relay stations, highway call boxes, and similar applications.

Japanese and U.S. companies became early leaders in PV manufacturing for uses both large and small. For example, Japanese firms such as Sharp and Kyocera

pioneered the use of solar cells in pocket calculators. A credit-card-sized solar-powered calculator from 1983 still helps us do quick calculations.

In the mid-1980s, Germany joined the United States and Japan in the race for PV production dominance, but by the early years of the new millennium, Japanese and U.S. companies accounted for roughly 70 percent of the world's PV output.

Forward-thinking energy policies in Germany were the catalyst that spurred solar power's astounding growth over the last decade or so. By guaranteeing renewable power producers access to the grid as well as a long-term premium price for their electricity, the German government's policy made going solar economically attractive. A reinvigorated German PV manufacturing industry climbed back into the number two spot behind Japan. As world production increased to meet demand, the price of solar panels dropped, helping to drive demand higher.

With demand for PV cells growing quickly, China—factory to the world—got into the game. Beginning around 2006, a boom in the Chinese PV industry massively expanded global production and drove prices down even further. Today China is a solar manufacturing giant, producing close to two thirds of the world's PV—more than the United States, Japan, and Germany combined.

The decline in PV panel prices over the decades is astonishing. In 1972, they cost over $74 per watt. The average price as of mid-2014 was less than 70¢ per watt—99 percent cheaper. (For reference, the typical U.S. rooftop system today has between 2 and 10 kilowatts of generating capacity. One kilowatt equals 1,000 watts.)

Around the world, solar installations are growing by leaps and bounds on residential and commercial rooftops and in solar farms, also called solar power plants or parks, that can cover thousands of acres. Between

2008 and 2013, as solar panel prices dropped by roughly two thirds, the PV installed worldwide skyrocketed from 16,000 to 139,000 megawatts. That is enough to power every home in Germany, a country with 83 million people. In its January 2014 solar outlook report, Deutsche Bank projected that 46,000 megawatts would be added to global PV capacity in 2014 and that new installations would jump to a record 56,000 megawatts in 2015.

The International Energy Agency in Paris, which is typically conservative in its renewable energy forecasts, has been revising its solar projections upward. As recently as 2011 it forecast 112,000 megawatts of solar generating capacity by 2015—a figure the world left far behind in 2013. The organization now projects that by 2018 the total will be 326,000 megawatts of generating capacity, but the world will likely come close to this in 2016.

As solar power installations spread, it is worth remembering a point often made in the energy literature to convey the sheer scale of the solar resource: The sunlight striking the earth's surface in just one hour delivers enough energy to power the world economy for one year.

The largest solar power projects in the world just five years ago seem small by today's standards. An 80-megawatt PV park in Canada was the largest when it was finished in 2010. Now there are utility-scale solar power plants being built with hundreds of megawatts of generating capacity. A planned Japanese project on a small island near Nagasaki will have a 430-megawatt capacity, for instance. In California, it is not unusual today to see solar power plants being built with 300–500 megawatts of generating capacity.

Deutsche Bank notes that as of early 2014, solar PV was already competitive with average residential, commercial, or industrial electricity rates in 14 countries and in California, even without subsidies. For example,

residential rooftop solar came in 25 percent cheaper than grid electricity in both California and South Africa—and at less than half the cost of power from the grid in Chile. In Italy, where PV systems now generate nearly 8 percent of electricity, solar was some two thirds cheaper than the grid average in both the residential and the industrial market.

Solar power also beats the average grid cost of electricity for the German residential and industrial markets. Germany is no tropical paradise. Indeed, its solar resource resembles that of rainy Seattle, Washington. But the government's policy commitment to renewable energy allowed Germany to become number one in installed PV capacity in 2005, a position it still held at the start of 2014. Some 1.4 million solar systems with a combined generating capacity of 36,000 megawatts, more than one quarter of world capacity, had been installed in Germany by then. Roughly 5 percent of the country's electricity was generated by solar panels in 2013. In the first 11 months of 2014, Germany's solar share rose to nearly 7 percent.

But solar power is about to have a new capacity leader. Annual installations in Germany and in Europe more broadly have slowed in recent years as incentives were reduced. Now China, which was slow getting started with PV installations, is going full-speed ahead. By more than doubling its PV generating capacity to 18,300 megawatts in 2013, China ousted Italy from the second place position. With planned 2014 installations adding up to 13,000 megawatts of new solar generating capacity, China is positioned to soon lead the world in capturing energy from the sun.

As governments see how quickly solar power can be installed, they may realize that their official capacity targets are too modest. China's initial goal for 2020 was to have 20,000 megawatts in operation. This was then

raised to 50,000 megawatts, but in May 2014 China stunned the world by announcing a new, even more ambitious goal: 70,000 megawatts by 2017.

In Australia, a major coal producer and exporter, coal accounts for roughly two thirds of electricity generation. Solar power is gaining importance in the energy mix, however, as PV prices fall and rooftop solar systems spread. By the beginning of 2014, one out of every seven Australian homes was using rooftop solar PV for electricity. In 2007 there were only 8,000 rooftop solar systems in Australia. Now there are over a million.

Part of the attraction for Australians in going solar is that residential electricity prices have soared. Beginning in 2009, power transmission and distribution companies spent some $45 billion (Australian) updating and expanding the electricity network in this spread-out country. Perhaps half of that money was spent to meet an anticipated surge in demand that never came, in part due to more people generating some of their own electricity with rooftop PV.

Largely because of this infrastructure overinvestment, customers are now paying twice as much for electricity from the grid as before. Australian energy journalist Giles Parkinson reported in July 2014 that residential solar costs range from 12¢ to 18¢ (Australian) per kilowatt-hour (kWh) and may soon drop below 10¢ per kWh. Meanwhile, monthly transmission and distribution charges alone come to 15¢ per kWh—that's more than half the average bill. The bottom line is that in a growing number of places in Australia, coal-fired power would not be able to compete with solar even if the coal itself were free.

In Japan, the adoption of solar technology in both residential and nonresidential sectors accelerated sharply following the Fukushima nuclear power disaster, due largely

to generous government solar incentives introduced after the accident. During 2013, Japan added nearly 7,000 megawatts of solar PV, doubling its installed PV generating capacity to 14,000 megawatts. This brought Japan halfway to its national solar goal for 2020. Some Japanese home builders are promoting solar houses to gain a competitive sales edge over other builders. Ichijo Co., a leading home builder, reported for example that 90 percent of the houses it sold in 2012 were equipped with solar panels.

Another sleeping giant, India, is waking up to its solar potential. By the start of 2014 it had 2,300 megawatts of PV generating capacity in operation, most of it in the sun-rich northwest desert states of Gujarat and Rajasthan. The official Indian goal, as set in 2010 by the National Solar Mission, is to have 22,000 megawatts of solar generating capacity in operation by 2022. In late 2014, India's energy minister stated that the government intends to boost the solar target to a startling 100,000 megawatts by 2022.

In December 2014 India's government approved a plan to facilitate the development of 25 "ultra-mega" solar parks of at least 500 megawatts each by 2019. State governments will choose developers and identify land for proposed projects, then apply to the federal Ministry of New and Renewable Energy for project approval. All told, the government aims to install some 20,000 megawatts of utility-scale PV in these parks. The 590-megawatt Charanka solar park in Gujarat—of which nearly 40 percent is now online—may be used as a model.

India's solar development will be partly funded by the recently doubled tax on coal mined domestically or imported into the country. This is a revenue transfer that simultaneously discourages the use of coal and provides investment capital for solar generation.

Another ambitious national solar goal comes from Saudi Arabia, where there are plans to develop some 41,000 megawatts of solar power by 2032. This will consist of 16,000 megawatts of power from solar PV and 25,000 megawatts from concentrating solar thermal power (a technology discussed in more detail later in this chapter). If these plants were in service today, they could supply up to two thirds of Saudi Arabia's electricity.

There is no national solar power capacity target in the United States, but PV is finally surging in the country that invented it. U.S. PV generating capacity jumped by a record 4,700 megawatts in 2013 to reach 12,000 megawatts overall, a growth of 65 percent. The market analysts at GTM Research projected another 6,500 megawatts would be added to U.S. solar capacity in 2014.

At the state level, California has long been the leader in developing solar energy resources. Other high-ranking states, in order of installed capacity, are Arizona, New Jersey, North Carolina, Massachusetts, and Nevada. This list shows, as we learned with Germany, that local solar intensity is only one of the influences on solar power development. Policy also plays a key role. New Jersey and Massachusetts, not especially sunny compared with the western states, have encouraged solar power through rebates for panel owners, renewable electricity mandates for utilities, and other policies. Contrast this with Florida, nicknamed "The Sunshine State." Policies that discourage PV adoption there have ensured that the state does not even appear on the top 10 list for total capacity.

Installing solar PV in the United States keeps getting more affordable. Between 2012 and 2013, U.S. residential rooftop PV system prices dropped 9 percent. For nonresidential systems, prices fell 16 percent. Prices continued falling in 2014. The overall price of PV system installations now depends much less on the price of the

panels and much more on other facets of the business, including the costs of labor, other equipment, and landing customers.

Recent studies of solar power in California and Connecticut indicate that signing up new customers should get easier—and therefore cheaper—because adopting solar power can be contagious. One author, Kenneth Gillingham at Yale, says, "We find that if a neighbor close to you installs solar, you're much more likely to install than if a neighbor four miles away [does]."

By late 2014 there were nearly 600,000 individual PV systems in the United States, almost twice as many as in 2012. This number may well pass 1 million in 2016.

Increasingly, U.S. residential rooftop installations are owned by someone other than the property owner. In these arrangements, the installer puts up and maintains the PV system and the customer either pays a long-term fixed rate for the electricity generated or leases the system itself. Both models eliminate major up-front expenditures for consumers. According to GTM Research, in 2013 two thirds of all U.S rooftop installations fell into these camps, up from just over 40 percent in 2011. As PV systems become ever more affordable, however, the market is beginning to shift back to direct ownership, with customers aided by solar-specific loans.

Solar power's rapidly improving economics are leading to a solarization of the U.S. housing sector. In 2013, just 12 percent of U.S. homebuilders offered solar panels as an option for new single-family homes. More than half of them anticipate doing so by 2016. For multifamily homes, two thirds of builders will offer solar systems by 2016, up from 45 percent in 2013.

Four of the top five U.S. home construction firms—D.R. Horton, Lennar Corp., PulteGroup, and KB Home—now automatically include solar panels on every new

house in certain markets, and they are rapidly expanding the practice as solar costs fall. In 100 of its subdivisions in California, for example, Lennar has included solar panels as standard. Soon the firm will do the same in developments in Colorado and several other states. Anyone buying one of these homes will be in the energy business.

Those for whom on-site solar power may not be a possibility—such as renters, condominium owners, or homeowners without the right rooftop conditions—can take advantage of the growing number of "community solar" options, where multiple participants have a stake in a shared PV project. The project may be owned by a utility or non-profit or by a new business venture formed by the community members themselves.

The rapid growth in private solar installations is leading to predictions of a "utility death spiral" in competitive electricity markets. As more customers in a utility's service area generate some of their electricity with rooftop PV, the utility loses money because it is selling those customers less of its product. And because PV generation displaces more expensive conventional electricity on the grid, it helps drive down power prices. This problem is especially acute in the midday hours when solar generation is strong and demand tends to be high, eroding the utility's formerly high peak-hour profits.

Even as it pulls in less money, the utility still has to run its plants and maintain its infrastructure, so it is then forced to raise its rates. This, along with the continued decline in solar system prices, encourages even faster growth in rooftop installations. Many utilities, with their old business model becoming obsolete, see distributed solar power as an existential threat. The question is whether to fight it or to adapt.

In Germany, impressive rooftop solar growth has helped put leading utilities on the ropes. It also has led

to some fascinating developments as they try to reinvent themselves to survive in the new energy economy. The two largest German utilities, E.ON and RWE, each saw their market value drop by more than half between 2009 and 2013. The massive expansion of PV and wind power—another fuel-free source with low costs of operation—together with weak power demand drastically reduced their income and made their centralized power plants uneconomic to run. Indeed, RWE chief of strategy Thomas Birr said, "At the current market price, it is virtually impossible to operate conventional power stations economically…20 percent to 30 percent of our power stations currently cannot even cover their operating costs."

As a result, E.ON and RWE are in the process of shutting down or idling 19,000 megawatts of coal and natural gas plants. And both firms are now required to quickly shut down their nuclear plants to comply with Germany's plan to phase out nuclear by 2022. RWE posted a $3.8 billion loss in 2013—its first since 1949—and E.ON took a $5.6 billion loss in 2014.

Faced with an unsustainable status quo, these energy giants are moving to adapt. RWE will become more of an energy services company, managing and integrating solar and other renewables on the grid, consulting on energy efficiency with homeowners and businesses, and selling energy-saving tools such as smart thermostats.

In late 2014, E.ON announced it was splitting off the centralized power generation part of its business into a new company. When the split is finalized in 2016, E.ON will then focus on renewables, efficiency, and the pairing of rooftop PV with battery storage—an even more disruptive technology because it would allow customers to more easily disconnect from the grid completely.

Of course, many utilities worried about what growing solar PV generation means for their business are fighting

back. One way that U.S. utilities are doing so is by attacking the net metering policies that now exist in 43 states. Under such a policy, when a utility customer's rooftop generation exceeds the household's needs, the surplus electricity is fed into the grid. The customer is credited for this excess electricity.

In late 2013, an Arizona utility became the first to gain traction against net metering. Arizona Public Service (APS), which says PV systems are being installed at a rate of more than 15 per day in the state, wanted customers with rooftop PV to pay a surcharge of up to $100 per month. After APS spent almost $4 million on ads in support of the proposal, regulators agreed to a much smaller surcharge, averaging $5 per month. By late 2014, measures to weaken or eliminate net metering policies had been proposed in at least 20 states. Some of these proposals were actually drafted by the American Legislative Exchange Council, a conservative political group whose members include representatives from the utility and fossil fuel industries.

Utilities trying to stifle solar power may soon realize that the effort is futile. The U.K.-based financial services firm Barclays downgraded the entire U.S. electricity sector in 2014, in part because in its view U.S. utilities are generally unprepared for the challenges posed by distributed solar power and battery storage. As Barclays analysts wrote, "whatever roadblocks utilities try to toss up... it's already too late."

The falling costs of solar-generated electricity are driving developments in the power sector at a pace that could not have been imagined even a few years ago. For example, in May 2014, Austin Energy, a publicly owned utility in Texas, signed a 150-megawatt power purchase agreement (a long-term contract to purchase electricity for a fixed price) with solar developer Recurrent Energy

for just under 5¢ per kWh. Thus the electricity produced by this PV installation, which will be the largest in Texas when completed in 2016, greatly undercuts the local utility's natural gas–generated electricity at 7¢, its coal-fired power at 10¢, and its nuclear power at 13¢. Austin Energy is planning to get 55 percent of its electricity from renewable sources by 2025, up from 23 percent in mid-2014.

Betsy Engelking, a vice president at Minnesota-based wind and solar power developer Geronimo Energy, says that the price of solar power has fallen "about five years faster than anyone expected it to." To say that the fast-improving economics of solar power is attracting attention is an understatement. Major investors, including Warren Buffett and Ted Turner, are plowing billions of dollars into solar power plants.

In January 2013, for example, Buffett gave solar energy a huge financial boost when his MidAmerican Energy Holdings Company announced an investment of up to $2.5 billion in California in what is now known as the Solar Star project. At 580 megawatts, it will become the world's largest PV project when complete in late 2015. MidAmerican had earlier bought the Topaz solar farm in California, now the world's largest at 550 megawatts. As of its completion in late 2014, Topaz can generate enough electricity to power 180,000 California homes. MidAmerican also took a 49 percent stake in the 290-megawatt Agua Caliente plant in Arizona.

Both Topaz and Agua Caliente use thin-film PV, made of a cadmium-telluride compound, rather than the traditional silicon-based PV. The supplier, First Solar, the world's leading thin-film maker, is a U.S. company that does most of its manufacturing in Malaysia.

Ted Turner has teamed up with Southern Power, a utility serving eight states from California to North Carolina, to acquire seven solar plants approaching a com-

bined 300 megawatts. The largest is a 140-megawatt solar park in Imperial County, California—another project using thin-film PV from First Solar—that began operating in October 2013.

Although photovoltaics are by far the most common way to convert the sun's energy into electricity, another approach is concentrating solar power (CSP), which uses mirrors to concentrate sunlight to drive conventional steam turbines or engines. The most prevalent CSP technology uses many rows of curved mirrors—"parabolic troughs"—to focus sunlight on fluid-filled tubes running the length of the troughs. The super-heated fluid then drives a steam turbine to generate electricity. Another kind of CSP is the "power tower," where a field of computer-operated mirrors concentrates sunlight on a central receiver to drive a steam turbine.

CSP generating capacity worldwide reached 4,100 megawatts in mid-2014. Spain and the United States totally dominate this source of electricity. Spain has dozens of small CSP plants, totaling 2,300 megawatts of capacity. The United States has more than 20 CSP plants, adding up to 1,500 megawatts, mostly in California and Arizona—both states with a high solar intensity.

One of the newer CSP facilities is the Solana plant in Arizona, a 280-megawatt parabolic trough plant. Ivanpah in California is the world's largest CSP plant, a power tower system with 390 megawatts of generating capacity. One of its attractions is that it can store up to six hours worth of heat energy in molten salts, enabling it to generate power long after sundown. Other recent additions to global capacity include the 100-megawatt Shams 1 plant in the United Arab Emirates; a 50-megawatt plant in Rajasthan, India; and the 10-megawatt first phase of a 50-megawatt plant being built in China's Qinghai Province.

In mid-2014 in Chile's Atacama Desert—known as the driest place on earth—the Spanish firm Abengoa began construction on a 110-megawatt CSP plant, a power tower with an impressive 18 hours of thermal energy storage in molten salts. If successful, this plant will be able to generate electricity around the clock.

Despite its remarkable promise for energy storage, CSP's ambition to become a prominent global energy source has faded somewhat in recent years as the cost of photovoltaics has fallen much faster. As a result, several prospective CSP projects in the United States have been cancelled or replaced by PV. CSP costs still are falling, however, dropping by one third between 2010 and 2013 to reach 13¢ per kWh. The U.S. Department of Energy's SunShot program has set a goal of helping CSP to be fully cost-competitive at 6¢ per kWh by 2020. By that year, global CSP capacity is expected to reach 11,000 megawatts, but it could be much higher if SunShot reaches its mark.

Most people around the world rely on electricity from large power sources, transmitted via an electric grid. For the roughly 1.3 billion people in the world living in communities not yet connected, it is now often cheaper and more efficient simply to install PV panels rooftop-by-rooftop than to build a central power plant and transmission infrastructure. India and Bangladesh provide some inspiring examples of how rural residents in developing countries are bypassing the grid.

Millions of rural Indians rely on highly polluting, poorly illuminating, and increasingly costly kerosene lamps for home lighting. Solar power offers a solution. SELCO Solar, an independent offshoot of the Washington, D.C.-based Solar Electric Light Fund, has installed roughly 200,000 solar home lighting systems in rural India since its launch in 1995. According to SELCO's

Surabhi Rajagopal, a typical system that replaces two kerosene lamps with compact fluorescent bulbs or LEDs and can charge a mobile phone costs roughly $200. This includes the cost of installation and one year of maintenance. Because households spend roughly $60 annually on kerosene and mobile charging, a new solar home system pays for itself in a little over three years. SELCO works with regional rural banks to set up a workable loan for the customer, with monthly payments lower than what lighting and phone charging used to cost. Nationally, India's official goal is to replace kerosene lamps with 20 million solar lighting systems, potentially reaching 100 million people.

Switching from kerosene lamps to solar cells is particularly helpful in fighting climate change. Although the estimated 1.5 billion kerosene lamps used worldwide provide less than 1 percent of all residential lighting, they account for 29 percent of the lighting sector's carbon dioxide emissions. Kerosene lamps burn the equivalent of 1.3 million barrels of oil per day, equal to roughly half the daily oil production of Kuwait. With the price of kerosene rising and the cost of solar cells declining, the decision to make the switch becomes progressively easier.

A similar argument can be made for the economic and climate advantages of electricity from rooftop solar installations over the far costlier electricity from diesel generators. According to the solar consultancy Bridge to India, solar generation in India costs about one third to one half as much as diesel generation. Whether used for lighting homes or pumping water, solar electricity has a strong advantage.

Solar electricity generating technology is also benefiting millions of people in Bangladesh who might never have access to power from the grid. World Bank–led efforts since 2002 have helped install 3 million solar

home systems. As of 2014, over 70,000 solar home systems were being installed every month. The World Bank's head person in Bangladesh, Christine E. Kimes, notes: "This is a proven model that works. Investing in electricity in rural areas empowers both men and women, leading to increased income and growth opportunities and reducing poverty."

When a villager buys a solar PV system, that person is buying a reliable, long-term supply of electricity. With no fuel costs and minimal maintenance needs, only the up-front outlay requires financing.

Another small-scale way to meet household energy needs with the sun is by using rooftop solar thermal collectors to heat water. China now has an estimated 2.8 billion square feet of rooftop solar water heaters installed, enough to supply 170 million Chinese households with hot water. This low-cost technology has leapfrogged into villages that do not yet have electricity. For roughly $300, villagers can install a rooftop solar collector and take their first hot showers.

In Europe, where energy costs are high, rooftop solar water heaters are also quite popular. In Austria, 15 percent of all households rely on them for hot water. Indeed, in some Austrian villages nearly all homes have rooftop collectors. Germany is also forging ahead. An estimated 2 million German homes are now relying on rooftop solar systems for water heating. Some 40 percent of these systems in Austria and Germany are combination systems, heating space as well as water.

Brazil is Latin America's leader in solar water heating, in part because of programs that require solar hot water systems in new housing for the very poor. The state of Hawaii in the United States has its own mandate, which took effect in 2010, stipulating that all new single-family home construction must include solar water heaters.

Solar hot water systems have taken hold in parts of the eastern Mediterranean too, where the island nation of Cyprus leads the world in rooftop solar collectors per person. And some 85 percent of Israeli households use their rooftops for water heating.

From the rooftops of homes, schools, businesses, and government buildings to sports stadiums, parking lots, former landfills, and deserts, a solar energy revolution is unfolding. The rapidly increasing competitiveness of PV in particular suggests that solar energy has an even more promising future than many analysts have expected. For much of humanity, it heralds cheaper electricity. But for many of the world's low-income residents, it means electricity in their homes for the very first time.

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