ANNALS OF A WARMING PLANET

4.6 BILLION YEARS ON, THE SUN IS HAVING A MOMENT

In the past two years, without much notice, solar power has begun to truly transform the world's energy system.

By Bill McKibben

July 9, 2025

Photograph by Hu Huhu / Xinhua / Redux

People have been telling stories about renewable energy since the nineteen-seventies, when the first all-solar-powered house opened on the campus of the University of Delaware, drawing a hundred thousand visitors in 1973, its first year, to marvel at its early photovoltaic panels and its solar hot-water system, complete with salt tubs in the basement to store heat overnight. But, even though we've got used to seeing solar panels and wind turbines across the landscape in the intervening fifty years, we continue to think of what they produce as "alternative energy," a supplement to the fossil-fuelled power that has run Western economies for more than two centuries. In the past two years, however, with surprisingly little notice, renewable energy has suddenly become the obvious, mainstream, cost-efficient choice around the world. Against all the big bad things happening on the planet (and despite all the best efforts of the Republican-led Congress in recent weeks), this is a very big and hopeful thing, which a short catalogue of recent numbers demonstrates:

- It took from the invention of the photovoltaic solar cell, in 1954, until 2022 for the world to install a terawatt of solar power; the second terawatt came just two years later, and the third will arrive either later this year or early next.

- That's because people are now putting up a gigawatt's worth of solar panels, the rough equivalent of the power generated by one coal-fired plant, every fifteen hours. Solar power is now growing faster than any power source in history, and it is closely followed by wind power—which is really another form of energy from the sun, since it is differential heating of the earth that produces the wind that turns the turbines.

- Last year, ninety-six per cent of the global demand for new electricity was met by renewables, and in the United States ninety-three per cent of new generating capacity came from solar, wind, and an ever-increasing variety of batteries to store that power.

- In March, for the first time, fossil fuels generated less than half the electricity in the U.S. In California, at one point on May 25th, renewables were producing a record hundred and fifty-eight per cent of the state's power demand. Over the course of the entire day, they produced eighty-two per cent of the power in California, which, this spring, surpassed Japan to become the world's fourth-largest economy.

- Meanwhile, battery-storage capability has increased seventy-six per cent, based on this year's projected estimates; at night, those batteries are often the main supplier of California's electricity. As the director of reliability analysis at the North American Electric Reliability Corporation put it, in the *CleanTechnica* newsletter, "batteries can smooth out some of that variability from those times when the wind isn't blowing or the sun isn't shining." As a result, California is so far using forty per cent less natural gas to generate electricity than it did in 2023, which is the single most hopeful statistic I've seen in four decades of writing about the climate crisis.

- Texas is now installing renewable energy and batteries faster than California; in a single week in March, it set records for solar and wind production as well as for battery discharge. In May, when the state was hit by a near-record-breaking early-season heat wave, air-conditioners helped create a record demand on the grid, which didn't blink—more than a quarter of the power came from the sun and wind. Last week's flooding tragedy was a reminder of how vulnerable the state is to extreme weather, especially as water temperatures rise in the Gulf, producing more moisture in the air; in late June, the director of the state's utility system said that the chances of emergency outages had dropped from sixteen per cent last summer to less than one per cent this year, mostly because the state had added ten thousand megawatts of solar power and battery storage. That, he said, "puts us in a better position."

- All this is dwarfed by what's happening in China, which currently installs more than half the world's renewable energy and storage within its own borders, and exports most of the solar panels and batteries used by the rest of the world. In May, according to government records, China had installed a record ninety-three gigawatts of solar power—amounting to a gigawatt every eight hours. The pace was apparently paying off—analysts reported that, in the first quarter of the year, total carbon emissions in China had actually decreased; emissions linked to producing electricity fell nearly six per cent, as solar and wind have replaced coal. In 2024, almost half the automobiles sold in China, which is the world's largest car market, were full or hybrid electric vehicles. And China's prowess at producing cheap solar panels (and E.V.s) means that nations with which it has strong trading links—in Asia, Africa, South America—are seeing their own surge of renewable power.

  In South America, for example, where a decade ago there were plans to build fifteen new coal-fired power plants, as of this spring there are none. There's better news yet from India, now the world's fastest-growing major economy and most

populous nation, where data last month showed that from January through April a surge in solar production kept the country's coal use flat and also cut the amount of natural gas used during the same period in 2024 by a quarter. But even countries far from Beijing are making quick shifts. Poland—long a leading coal-mining nation—saw renewable power outstrip coal for electric generation in May, thanks to a remarkable surge in solar construction. In 2021, the country set a goal for photovoltaic power usage by 2030; it has already tripled that goal.

- Over the past fifteen years, the Chinese became so skilled at building batteries—first for cellphones, then cars, and now for entire electric systems—that the cost of energy storage has dropped ninety-five per cent. On July 7th, a round of bidding between battery companies to provide storage for Chinese utilities showed another thirty per cent drop in price. Grid-scale batteries have become so large that they can power whole cities for hours at a time; in 2025, the world will add eighty gigawatts of grid-scale storage, an eightfold increase from 2021. The U.S. alone put up four gigawatts of storage in the first half of 2024.

There are lots of other technologies vying to replace fossil fuels or to reduce climate damage: nuclear power, hydrogen power, carbon capture and storage; along with renewables, all were boosted by spending provisions in Biden's Inflation Reduction Act and will be hampered to varying degrees by congressional rollbacks. Some may prove useful in the long run and others illusory, but for now they are statistically swamped by the sheer amount of renewable power coming online. Globally, roughly a third more power is being generated from the sun this spring than last. If this exponential rate of growth can continue, we will soon live in a very different world.

All this suggests that there is a chance for a deep reordering of the earth's power systems, in every sense of the word "power," offering a plausible check to not only the climate crisis but to autocracy. Instead of relying on scattered deposits of fossil fuel—the control of which has largely defined geopolitics for more than a century—we are moving rapidly toward a reliance on diffuse but ubiquitous sources of supply. The sun and the wind are available everywhere, and they complement each other well; when sunlight diminishes in the northern latitudes at the approach of winter, the winds pick up. This energy is impossible to hoard and difficult to fight wars over. If you're interested in abundance, the sun beams tens of thousands of times more energy at the earth than we currently need. Paradigm shifts like this don't come along often: the Industrial Revolution, the computer revolution. But, when they do, they change the world in profound and unpredictable ways.

In fact, the sheer scope of that potential change seems to be motivating much of the current backlash against clean energy in the U.S. Donald Trump's "Big Beautiful Bill" is disconcerting on many fronts but none more

so than in its attempt to repeal the energy future by ending the I.R.A. credits for solar panels and E.V.s; it has already put a serious crimp in what six months ago was a fast-developing domestic solar industry. (The stock price for Sunrun, the country's biggest residential-solar developer, fell forty per cent on a single day in June, after a new version of the Senate bill cut tax credits even more dramatically than expected.) An analysis from the Rhodium Group think tank found that by 2035 the bill may have eliminated as much as seventy-two per cent of all the clean electricity that would have been produced in the U.S. under the current law. But, in a way, even this backlash is a backhanded recognition of the moment; the Administration, and its supporters in the fossil-fuel industry, clearly consider this the last possible moment to stifle the sun.

To understand how we got here, you don't need to go very far back in time. In the postwar years, the U.S. enjoyed the greatest spurt of wealth in history, and most of it centered on fossil fuel. We built a new nation on cheap oil—one of sprawling suburbs, defined by countless cul-de-sacs and connected by a network of roads that eventually fed into the new interstate highways. You can see why Trump, who was young in those years, is still obsessed with petroleum. "I call it liquid gold," he said in March. "We're going to make more money than anybody's ever made with energy."

But, in those same postwar years, something else was developing. It was at Bell Labs in Murray Hill, New Jersey, that, on April 25, 1954, a trio of researchers announced the invention of the first practical photovoltaic cell: a silicon-based device that managed to convert about six per cent of the sunlight that fell on it into usable energy. The news made the front page of the *Times*, albeit below the fold (right next to a story about the launch of the field trials for Jonas Salk's polio vaccine). Under the headline "Vast Power of the Sun Is Tapped by Battery Using Sand Ingredient," the *Times'* reporter described a "simple-looking apparatus made of strips of silicon, a principal ingredient of common sand. It may mark the beginning of a new era, leading eventually to the realization of one of mankind's most cherished dreams—the harvesting of the almost limitless power of the sun for the uses of civilization." The sun, the article noted, "pours out daily more than a quadrillion kilowatt hours of energy, greater than the energy contained in all the reserves of coal, oil, natural gas and uranium in the earth's crust."

At first, solar power was so expensive that it only made sense to use it where nothing else would work: in outer space, mainly, where it powered satellites. But, as the years went on, the cost came down fairly steadily. President Jimmy Carter gave the technology a big boost, proposing measures that, until the Reagan Administration reversed them, aimed to insure that by 2000 solar power supplied twenty per cent of America's energy. Then, around the turn of this century, the German Green Party leveraged its parliamentary power to win a big government subsidy for rooftop solar power, creating a demand that led China, which was then building one coal plant after another for its own use, to start manufacturing solar panels in bulk for export to Europe. Solar cells were, like computer chips, a paradigmatic example of the learning curve: the more you produced, the better you got at it, making them constantly cheaper. Earlier this decade, power distilled from the sun and wind became cheaper to produce than the power that comes from fossil fuels; China was the first to realize this; hence its rapid conversion to renewables.

If you want to assign a precise moment when the results of that new economic reality became manifest, consider June, 2023. That month was when scientists reported that the earth's temperature had suddenly begun not just to climb but to spike—the days around the solstice were the hottest ever measured, setting off a run of record-smashing heat that continues to this day. But June, 2023, also seems to be the month when people started putting up a gigawatt's worth of solar panels every day.

To get a sense of the deeper reason that the transition is so important, consider how a solar panel works. As *The Economist* described it recently, "a photovoltaic cell is a very simple thing: a square piece of silicon typically 182 millimetres on each side and about a fifth of a millimetre thick, with thin wires on the front and an electrical contact on the back. Shine light on it and an electronic potential—a voltage—will build up across the silicon. . . . Run a circuit between the front and the back, and in direct sunlight that potential can provide about seven watts of electric power." There's silver dust in the cells, and some boron and phosphorus, critical additives to increase conductivity and to provide the necessary environment for photons from sunlight to knock electrons loose from the silicon. That's what creates the power: a tiny reaction which gets endlessly magnified.

Scientists call electricity produced this way "work energy," as opposed to "heat energy," which comes from burning wood or fossil fuels, and it is a far more efficient way of getting things done. As a report published last fall by the Rocky Mountain Institute explains, "Burning gas to light a room creates more heat than light. Burning coal to create electricity creates more heat than electricity. Burning oil to move a vehicle creates more heat than motion. We are sending more energy up smokestacks and out exhaust pipes than we are putting to work to power our economy." This is not hyperbole: burning oil to power a car or burning coal to produce electricity is at best slightly more than thirty per cent efficient—or seventy per cent inefficient. For that reason, it takes two to three times more energy to run a standard car than to run an E.V., which is why even an E.V. charged with power from a coal-fired plant is still far more efficient than a vehicle run on an internal-combustion engine. E-biking—best thought of as biking without hills—may prove to be an even more important innovation. The e-bike is almost unbelievably efficient: to fully charge a five-hundred-watt e-bike costs, on average, about eight cents. That charge provides some thirty miles of range, so it costs about a penny to ride five miles.

Work energy turns out to be better than heat energy even for providing heat. An electric heat pump is three to five times as efficient as the gas boiler that sits in most American basements. Essentially, the pump takes the heat in the air outside your house, extracting it with a compressor to heat the air inside. (In the summer, it runs in reverse, to cool the house down.) It's mostly pumping heat, not producing it. Last year, for the third year straight, heat pumps outsold furnaces in the U.S.

Taken together, all this has built huge momentum. As the energy investor Rob Carlson put it recently, continuing to burn fossil fuels is a "self-imposed financial penalty" which will "ultimately degrade the country's long-term global competitiveness. The same calculation applies to any nation, or any polity of any

size, that chooses to continue burning fossil fuels in any application in which electricity could instead be provided more competitively with renewables." This logic is so strong that even Saudi Arabia, the U.A.E., and Qatar are building vast fields of solar panels; in January, Oilprice.com reported that, by 2050, half the region's electricity would come from photovoltaics, up from two per cent in 2023, even as those nations hope to keep pumping and exporting oil and gas.

In retrospect, it's reasonably easy to see how fast solar and wind power were coming. But, blinkered by the status quo, almost no one actually predicted it. In 2009, the International Energy Agency predicted that we would hit two hundred and forty-four gigawatts of solar capacity by 2030; we hit it by 2015. For most of the past decade, the I.E.A.'s five-year forecasts missed by an average of two hundred and thirty-five per cent. The only group that came even remotely close to getting it right was not J. P. Morgan Chase or Dow Jones or BlackRock. It was Greenpeace, which estimated in 2009 that we'd hit nine hundred and twenty-one total gigawatts by 2030. We were more than fifty per cent above that by 2023. Last summer, Jenny Chase, who has been tracking the economics of solar power for more than two decades for Bloomberg, told the *Times*, "If you'd told me nearly 20 years ago what would be the case now, 20 years later, I would have just said you were crazy. I would have laughed in your face. There is genuinely a revolution happening."

One reason we missed some of that revolution is that so much of it is taking place in China. By some measures, as Bloomberg's David Fickling worked out, seven Chinese companies that I'd wager most Americans have never heard of—Tongwei, GCL Technology Holdings, Xinte Energy, Longi, Trina Solar, JA Solar Technology, and JinkoSolar—produced more energy in 2024 than the seven global giants at the heart of Big Oil. In 2020, China set a goal of producing twelve hundred gigawatts of clean power by 2030; it hit that target in early 2024, six years ahead of schedule.

Across Europe, renewables surged dramatically in 2024; the war in Ukraine has pushed the Continent toward controlling its own energy destiny. The United Kingdom—where, after all, fossil fuel really began—now has so much wind power that in 2024 its carbon emissions fell below what they were in 1879, a year that saw the start of the Anglo-Zulu War and the marriage of Prince Arthur, Queen Victoria's seventh child, to Princess Louise Margaret of Prussia. On the last day of September, England shuttered its last remaining coal-fired power station, at Ratcliffe-on-Soar, in Nottinghamshire, with the blessings of the local unions, which said that their workers had been offered alternate job training. Some may end up working in what the plant's owner, a company called Uniper, described as a "low-carbon energy hub" to be built on the site.

And, though it took centuries for the fossil-fuel revolution to extend from the centers of empire, in some countries solar power is showing signs of leapfrogging combustion, the way that cellphones reached many places before landlines did. The Pakistan example is perhaps the most dramatic. As 2024 began, demand for electricity on the national grid started falling—not because the economy was in decline but because (as careful scrutiny of images on Google Earth revealed) so many Pakistanis were putting up solar panels. As one

Lahore-area corn farmer, Mohammad Murtaza, told Bloomberg, pointing to his own photovoltaic array, "I have never seen such a big change in farming. Ninety-five percent of farmland has switched to solar in this area." Many farmers can't afford metal mounting brackets for the panels, which are more expensive than the panels themselves, so they just lay the panels on the ground, cells to the sun.

If you have travelled through rural Asia, you know the sound of diesel generators pumping the millions of deep tube wells that were a chief driver of the agricultural Green Revolution of the nineteen-sixties and seventies. Now solar electricity is pumping the water—diesel sales in Pakistan apparently fell thirty per cent in 2024. If you're a farmer, that's kind of a miracle; fuel, one of your biggest costs, is simply gone. As Waqas Moosa, a Pakistani solar entrepreneur told the American journalist David Roberts, in February, "a three-kilowatt inverter with, you know, maybe four or five panels" is now routinely included in a bride's dowry.

If you want to know *how* Pakistanis learned to put up all those panels, the longtime solar advocate Danny Kennedy just came back from a trip there and explained it to me in an e-mail. "Training programs, tips, and tricks hotlines & such sprang up," as people around the country started sharing notes, "so that tens of thousands of electricians and others could get into the game." He forwarded a selection of TikTok videos set to Punjabi music, showing electricians unboxing inverters and comparing Chinese panel brands. Renewables First, a think tank based in Islamabad, noted in a June report that the Pakistan example is particularly significant because the sale of Chinese solar panels is "cannibalizing demand from the very coal plants China financed" in that nation just a few years ago, as part of its New Silk Road, making it a "litmus test for China's global climate leadership." The report added, "By treating Pakistan as a proving ground for managing stranded fossil assets while scaling renewable ecosystems, China has the opportunity to develop and validate transition models that could be exported across the Global South."

Indeed, something similar seems to be playing out across Africa. Last summer, Joel Nana, a Capetown-based energy analyst, was struggling, as the Pakistan-watchers had been six months earlier, to understand new data. "In Namibia, we've uncovered that people have built about seventy megawatts of distributed generation, mostly rooftop solar—that's the equivalent of about fifteen per cent of the country's peak demand. In Eswatini, which is a very small country, it's about eleven per cent of peak demand," he told me. In South Africa, the continent's economic colossus, small-scale solar now provides, by his reckoning, nearly a fifth the capacity of the national grid. "You won't see these numbers anywhere," Nana said. In Namibia and Eswatini, "they're not reported in national plans—no one knows about them. It's only when you speak to the utilities. And, in fact, the numbers could be much higher, because the smallest systems aren't reporting to anyone, not even the utilities."

Here, again, the switch is being driven by the desire for reliable and affordable power. In April, 2024, for instance, Nigeria's electrical grid had its fifth blackout of the year. Nigerian businesses survive because they have backup diesel generators—in fact, those "backup" generators can supply far more power than the national grid. But it's expensive to keep pouring diesel into the tank, so "solar has become a no-brainer for most

businesses, if not all. The prices just make sense," Nana said. "In a lot of places, it's all the malls, all the mills—any business that has enough roof space." Many African countries have well-established trade networks with China, so the panels have come flooding in. "You have some utilities, like in Mozambique," Nana added, that see small-scale solar power as "a threat and are trying to claw it down. But the realization is this is happening anyway, whether you like it or not. If you fight people, they'll just go clandestine and install it without letting you know."

Forecasters are still a little in the dark, then, as to how fast solar is growing. But here's the current prediction from the I.E.A.: by 2026, solar will generate more electricity than all the world's nuclear plants combined. By 2029, it will generate more than all the hydro dams. By 2031, it will have outstripped gas and, by 2032, coal. According to the I.E.A., solar is likely to become the world's primary source of all energy, not just electricity, by 2035. But the I.E.A. also estimates that if we are to keep on the climate track set out in the Paris agreement in 2015—heading for a net-zero carbon world by 2050—we need to increase the pace at which we're installing renewables by about twenty per cent. So it's worth asking two questions: What might slow this revolution down, and how might we speed it up?

Some experts feared that we might run out of the minerals necessary to build the panels and turbines and batteries, but that fear seems to be fading: just in the past few years, for instance, vast new sources of lithium, an essential ingredient of most of the world's batteries, have been found; the price of most of the minerals needed for the energy transition has fallen even as the demand for them has soared. And, although getting them will involve scraping and gouging the earth, the scale of that destruction is far less than what we're doing now. (The dangers facing the men, women, and sometimes children who labor in the mines in nations such as the Democratic Republic of the Congo is a separate issue that must also be addressed.) According to a 2023 report from the Energy Transitions Commission, all the materials needed to reach net zero by 2050 will be less than the amount of coal consumed in a year. Lithium, once mined, does its job for decades; coal just gets burned, which means you have to mine more. And, when batteries or solar panels degrade, the minerals in them remain valuable enough that they will almost certainly be recycled—large-scale recycling operations are appearing around the world. (One of the biggest in the U.S. is run by a Tesla alumnus in Nevada.) A report from the Rocky Mountain Institute predicted that by 2050 we will have done all the mining we'll need to do for battery minerals; after that, we'll just recycle them, over and over again.

That seems an unlikely claim—even the best recycling systems currently recover only about ninety-five per cent of the minerals—but with each passing year we learn to build batteries with less lithium, less cobalt, and less nickel, and solar panels with less silver. Improving that efficiency by six to ten per cent a decade is enough to offset the recycling losses, and we're doing far better than that already. The Rocky Mountain Institute report states, "Such a closed-loop supply system means we can continue to derive value from battery minerals for centuries. Over the next 20 years, we will gather minerals not just to power the energy system of 2050 but also through to 2100 and beyond."

This combination of recycling and increasing efficiency makes for a kind of mind-blowing virtuous cycle. Consider the roof of my house, in Vermont, where I first installed solar panels a quarter-century ago. The frames and wiring on those panels will eventually degrade from sitting out in the weather; they're warrantied for twenty-five years, though in many places they last much longer. But, when I take them down, they'll be like small mines. In 2004, according to Germany's state-owned Fraunhofer Society, Europe's largest institute of applied-engineering research, one watt of solar power required about sixteen grams of polysilicon; this has dropped now to about two grams. As Hannah Ritchie, a data scientist and a senior researcher at Oxford University, calculated recently, "the silver used in *one* solar panel built in 2010 would be enough for around five panels today." By 2035 or so, when my oldest panels may have started to go out of service, the minerals that each contains will almost certainly be enough for ten new panels.

The other major potential limit is land. We can and should produce a good deal of our energy from rooftop solar panels and solar canopies over parking lots—but there aren't enough of either to produce all that we need, and it's considerably cheaper to use cleared land. Like, for example, some of the fields currently used to grow corn, the most widespread crop in America—particularly those used to grow corn for ethanol. Converting some of these fields to solar panels makes enormous ecological sense. As more than two hundred scientists at thirty-one colleges and universities across Iowa pointed out in 2023, a "one-acre solar farm produces as much energy as 100 acres of corn-based ethanol." In April, researchers at Cornell University's College of Agriculture and Life Sciences noted that all the corn grown for ethanol in the U.S. takes up about thirty million acres, an area roughly the size of New York State. If forty-six per cent of that land were converted to producing solar energy, they found, it would generate enough electricity for the U.S. to decarbonize its system by 2050.

The other question—how to speed up the transition—is interesting, too. Doubtless the price of solar panels and other equipment will continue to fall, but they're already so cheap that price is not usually the barrier, at least in places that don't have to pay huge tariffs. Instead, the blockages come from policy and infrastructure: there are nearly enough renewable projects on the books to power the United States entirely from renewables, but they wait in an "interconnection queue" for utility companies to approve them. The Biden Administration was committed to reducing these blockages—a special team in the White House constantly tracked the biggest choke points and wrangled state permits. The Trump Administration is actively trying to impede such progress; at a June congressional hearing, the Secretary of Energy (and former fracking executive), Chris Wright, said that solar and wind power were intermittent and hence were "just a parasite on the grid." In May, he issued orders keeping a coal plant in Michigan and an oil-and-gas-fired plant in Pennsylvania from being retired as planned.

This kind of obstruction is not slowing renewable energy in the rest of the world: if anything, Washington's new fickleness provides one more reason to stop depending on the U.S. for fuel. America is currently the world's largest exporter of natural gas; the Trump Administration is trying to supercharge that trade with the threat of tariffs on countries that don't increase their purchases. But, as one Wall Street analyst predicted this

spring, it's possible that renewables will see yet another acceleration, driven not just by climate worries but by security fears, as nations seek some insulation from "geopolitical, macro, and financial risks." A 2023 poll by the market research firm Glocalities, of twenty-one thousand respondents in twenty-one countries, found that sixty-eight per cent favored solar energy, "five times more than public support for fossil fuels." And surveys conducted by the communications and research firm Global Strategy Group in the fall of 2024 found that eighty-seven per cent of Americans—and almost eighty per cent of people planning to vote for Trump—favored the clean-energy tax credits in the I.R.A. "Solar power remains the most popular source of electricity in America," the Global Strategy Group partner Andrew Baumann said, "with broad support across the political spectrum." If we can make the transition affordable and easy, the will is there.

The power is there as well. Scientists are confident that the sun will burn for another five billion years. Our local star, which already provides heat and light and photosynthesis, is prepared to offer us all the energy we could ever use, and in the process perhaps help rescue us from an otherwise impossible moment. ♦

This is drawn from "Here Comes the Sun: A Last Chance for the Climate and a Fresh Chance for Civilization."

New Yorker Favorites

- The best movies, books, TV shows, albums, jokes, and podcasts of 2025.
- Holiday gift guides for kids, coffee nerds, food lovers, nostalgists, tech enthusiasts, and your host.
- When an Ivy League school turned against a student.
- How to cycle like a Dutchman.
- The day the dinosaurs died.
- The brothers behind Warner Bros.

Sign up for our daily newsletter to receive the best stories from *The New Yorker*.

Bill McKibben is a contributing writer at The New Yorker focussing on climate policy. His books include "Here Comes the Sun: A Last Chance for the Climate and a Fresh Chance for Civilization" (August, 2025).

More: Solar Power Renewable Energy Technology