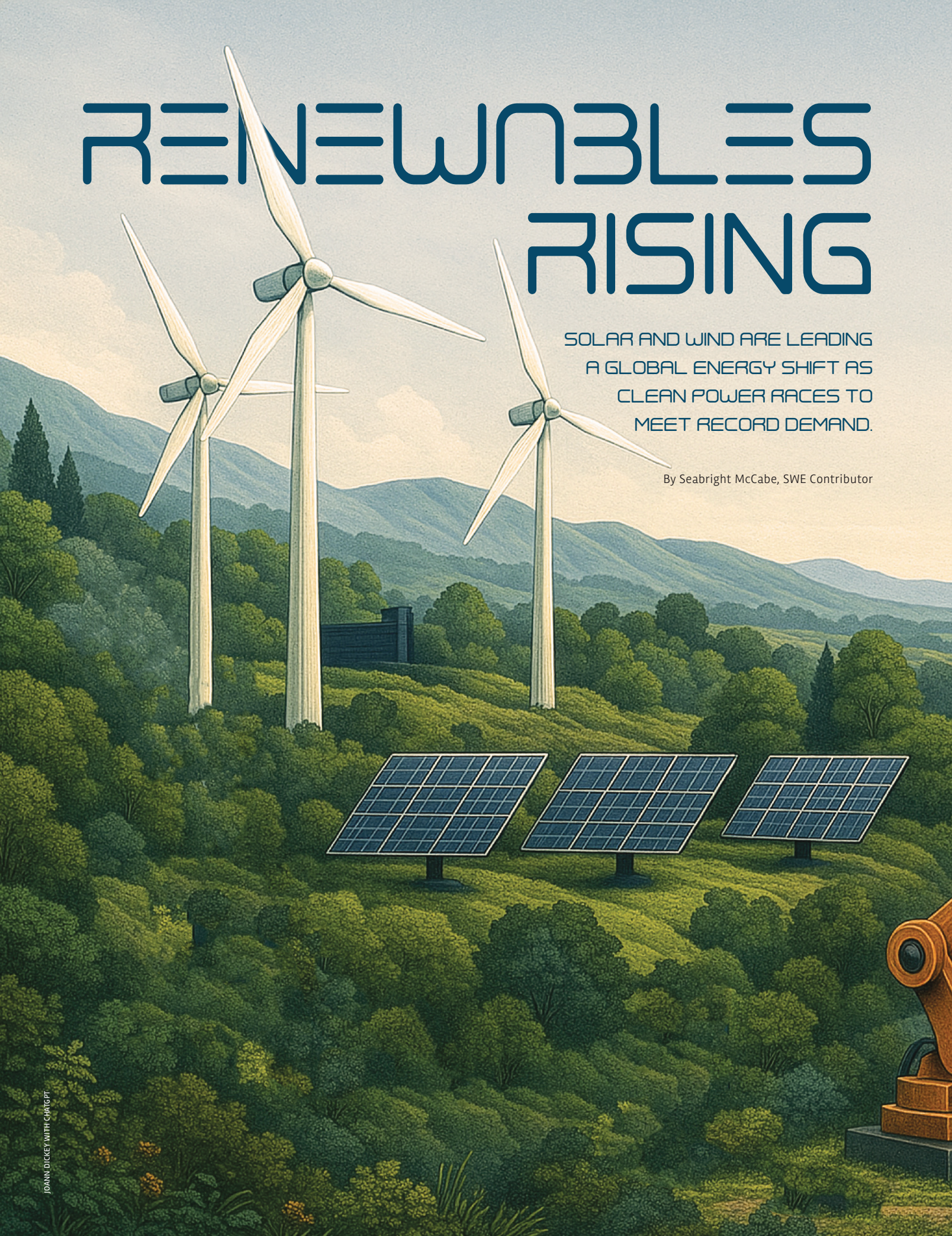


RENEWABLES RISING



SOLAR AND WIND ARE LEADING
A GLOBAL ENERGY SHIFT AS
CLEAN POWER RACES TO
MEET RECORD DEMAND.

By Seabright McCabe, SWE Contributor

In 2024, the rapid development of artificial intelligence and its energy-gobbling data centers, the evolving electrification of transportation, increased use of heat pumps, and expansions in manufacturing drove global electricity demand higher. By 2030, that demand is expected to increase by another 25%, according to global climate think tank Ember, which aims to accelerate the clean energy transition using data and policy efforts. Hotter temperatures due to the climate crisis have also spurred increases; Ember estimates nearly one-fifth of the global demand increase in 2024 was temperature-related. Despite a small uptick in fossil fuel-generated power, renewables were able to supply 96% of that increase in demand.

“In the first half of 2025, renewables, led by solar and wind power, exceeded the world’s electricity demand growth for the first time,” says Malgorzata Wiatros-Motyka, Ph.D., senior electricity analyst for Ember. In Ember’s report “Global Electricity Review 2025,” Dr. Wiatros-Motyka noted: “This marks the beginning of a shift where clean power is keeping pace with demand growth. As costs of technologies continue to fall, now

is the perfect moment to embrace the economic, social, and health benefits that come with increased solar, wind, and batteries.”

Renewables plus nuclear facilities generated more than 40% of the world’s electricity in 2024, adding a record 858 terawatt-hours (TWh) of generation, according to the report. Of that number, solar contributed more than half, and fast growth is projected to continue. How fast? Solar technology took decades to reach 1 TWh in 2022 but reached 2 TWh just two years later — a growth rate unseen from any power source in history.

“The world is watching how AI and EVs [electronic vehicles] will drive electricity demand. It’s clear that booming solar and wind are comfortably set to deliver,” Phil MacDonald, co-founder and managing director of Ember, wrote in the report. “The era of fossil fuel growth is coming to an end, even in a world of fast-rising demand.”



Coal hits terminal decline

Coal, among the most polluting fossil fuels when burned, generated 34% of the world's electricity last year, according to the U.S. Energy Information Administration. This was largely due to China's reliance on coal for 60% of its power generation, though that figure declined slightly in the first half of 2025. However, China also leads the world in solar energy capacity.

In the U.S., renewables have topped coal generation in another historic first. "Even with executive orders and subsidies meant to prop up the coal industry, roughly 93% of new energy projects that came online last year were wind and solar, and that trend is expected to continue through 2025," says Michelle Solomon, Ph.D., manager of electricity policy for Energy Innovation Policy and Technology LLC, a nonpartisan clean energy research and analysis group.

"Coal infrastructure is old, unreliable, and not designed for the flexibility the grid needs to bring resources on and off-line quickly," Dr. Solomon says. "When you look at all those factors, it's unlikely that coal power will recover, and wind and solar are only going to grow."

Solar crushed coal in the European Union last year, with coal falling by 26% — its largest global drop. And the EU's power sector emissions decreased to 585 million tons of CO₂, less than half of its peak in 2007. India is yet another 2024 success story, with coal meeting only 64% of its electricity demand growth compared to 91% just the year before.

Solar soars into the record books

As component manufacturing ramps up, wind and solar technologies have plummeted in cost. In 2024, solar photovoltaic (PV) tech was 41% cheaper on average than the lowest-cost fossil fuel alternatives, such as gas, while onshore wind projects were 53% cheaper, according to the International Renewable Energy Agency (IRENA).

Though wind and solar are intermittent, their energy can be stored in batteries, which have dropped 93% in price since 2010, due to economies of scale and the rising adoption of lithium iron phosphate, which eliminates the need for mined nickel and cobalt.

Ember reports that in the first half of 2025, solar power met 83% of new global electricity demand, while wind power grew by 7.7%. And the International Renewable Energy Agency projects that "by the end of this decade, solar PV is set to become the largest renewable source, surpassing both wind and hydropower, which is currently the largest renewable generation source by far."

For the last two decades, China has led the world in electricity demand, and, along with India, is determined to break the link with fossil fuel generation by accelerating the adoption of renewables, especially solar. China added more wind and solar capacity in 2024 than the rest of the world combined, and India began to cut its dependence on coal, according to Ember.

While the numbers and projections for solar are historic, they don't fully

include solar installations on homes and commercial buildings in developing countries. In Pakistan, for example, amid high electricity prices and an unreliable grid, rooftop solar capacity reached 5.3 gigawatt (GW), making it the country's largest energy source.

Worldwide, wind power capacity has tripled since 2015, according to IRENA. It is now the second fastest-growing renewable, with 35 countries getting more than 10% of their power from wind in 2024. Growth has been fastest in China with a 106 TWh increase followed by the U.S. with 32 TWh. Overall, European Union countries lead in shares of wind generation. Denmark generated 58% of its electricity from wind in 2024. The top 10 also includes Ireland, Portugal, Germany, the Netherlands, Finland, Sweden, and Spain.

Change takes political will

The U.S. has reversed its support for many renewables since President Donald Trump's reelection. In a September 2025 address to the United Nations, he called the climate crisis "the greatest con job ever perpetrated on the world." The U.S. Department of Energy has banned the terms "green, sustainability, climate change" and "emissions reduction" in its communications.

Tax credits, incentives, research grants, and projects funded by Congress under the Biden administration's bipartisan Inflation Reduction Act (IRA) are being canceled under the One Big Beautiful Bill Act. Only geothermal, hydropower, nuclear, and battery storage projects have largely escaped the budget ax. In response to looming cuts and expiring incentives, states are scrambling to implement projects currently in the pipeline by streamlining permitting, procurement, and construction.

"The IRA had a wealth of individual policies that were meant to support renewable energy projects and encourage more," Dr. Solomon says. "Most importantly, [it] created certainty by extending tax credits for 10 years



"I DO THINK THAT WE HAVE PASSED A TIPPING POINT. WE NEED MORE ENERGY, AND WHAT'S COMING ONLINE RIGHT NOW ARE WIND, SOLAR, AND BATTERY STORAGE."

— Michelle Solomon, Ph.D.

WOOD MACKENZIE



“ALTHOUGH THE U.S. HAS THE DOMESTIC MANUFACTURING FOR WIND POWER IN PLACE, THE GRID INFRASTRUCTURE IS LACKING. ONE OF THE BIGGEST OPPORTUNITIES FOR THE U.S. IS TO EXPAND GRID INFRASTRUCTURE ON A FEDERAL LEVEL, SO IT DOESN'T HAVE THE BUREAUCRACY AND MILESTONES THAT TODAY'S TRANSMISSION LINES HAVE TO GO THROUGH.”

– Leila Garcia da Fonseca

instead of one or two. Especially for wind power, there had been a cycle of credits expiring and then coming back. Uncertainty spikes the risk level and cost of financing, which increases the cost of the project.

“Defunding or reducing funding is not likely to benefit the economy long term,” she says. “The IRA took a careful approach to protect renewables R&D from political winds as much as possible. A lot of that is now gone.”

Dr. Solomon believes that despite the cuts called for in the current administration's tax and spending act, momentum toward renewables will keep growing. “I do think that we have passed a tipping point,” she says. “We need more energy, and what's coming online right now are wind, solar, and battery storage.”

Globally, Dr. Solomon points to very different policy environments. “In other countries, renewable energy and climate policies are not so subject to political swings,” she says. “They also have national climate goals. Though some U.S. states have climate goals, there's no clear national policy.”

“Having stable policies and clear goals is high level, but it trickles down to everything else,” she explains. “For instance, in the U.K. and Australia, there's a much more cohesive transmission and interconnection policy to expand the grid to prepare for renewable energy. And manufacturing in Asia is very robust due to incentives.”

Leila Garcia da Fonseca, renewables research director for the global research

and consultant Wood Mackenzie Power and Renewables, agrees. “China has demonstrated that certainty and the power of scale,” she says. “They set very ambitious targets for wind and solar and backed them up with massive investment in domestic manufacturing and grid infrastructure.”

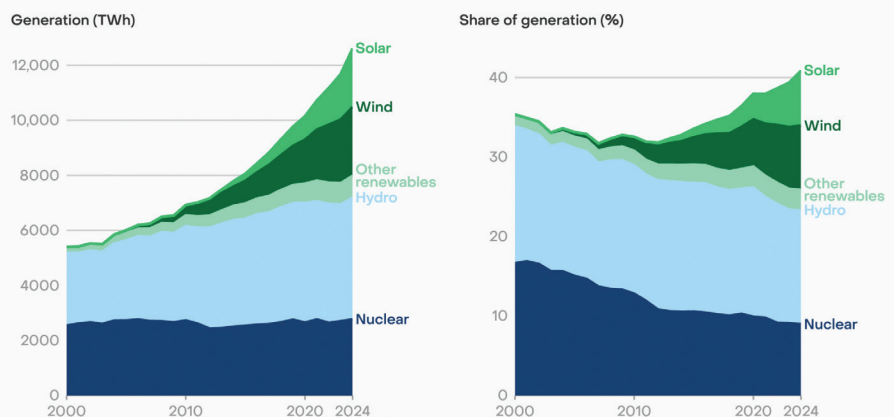
“The European Union focused on policy stability, streamlining permits, creating renewables acceleration areas, and investing in cross-border grid integration,” she continues. “Countries share power across borders, making it easier to balance supply and demand. One of the biggest opportunities for the U.S. is to expand its regional energy markets.”

Anywhere the wind blows

While China has the highest installed wind-power capacity by far, the U.S. leads the Americas with 160 gigawatts of onshore wind capacity installed. “It's also the only market in the Americas to have any offshore wind in operation,” da Fonseca says. “Right now, we have about 200 megawatts of offshore wind, and by the end of the year, it will be around 700 megawatts. We anticipate another 6 gigawatts of offshore capacity under operation over the next 10 years.”

Brazil follows with 32 gigawatts, about 75% of Latin America's capacity. There, wind stands in for hydropower during times of drought. Argentina and Chile

Renewable power growth pushed clean electricity above 40% of the global mix in 2024.



Source: Yearly electricity data, Ember
‘Other renewables’ includes bioenergy, geothermal, tide and wave energy

EMBER



“WITH 95% OF ITS SUPPLY CHAIN MADE IN THE U.S., GEOTHERMAL HAS INCREDIBLE POTENTIAL TO HELP STABILIZE THE GRID BY OFFSETTING ENERGY SOURCES LIKE SOLAR, WIND, AND OTHER INTERMITTENT TECHNOLOGIES. AND THERE’S A SKILLED WORKFORCE READY TO GO THAT IS TRANSITIONING FROM THE OIL AND GAS INDUSTRY.”

– Vanessa Robertson

are also ramping up development. To the north, Canada produces 18 gigawatts.

“Although the U.S. has the domestic manufacturing for wind power in place, the grid infrastructure is lacking,” da Fonseca says. “One of the biggest opportunities for the U.S. is to expand grid infrastructure on a federal level, so it doesn’t have the bureaucracy and milestones that today’s transmission lines have to go through.”

AI and data centers are the primary drivers of the anticipated demand surge. “The U.S. data center pipeline grew from 50 gigawatts in 2024 to 134 gigawatts in 2025,” da Fonseca notes. “That alone increases U.S. electricity demand by 12%, and utilities have committed to around 60 to 65 gigawatts of

new capacity to support this. Wind will be very competitive in terms of levelized cost of energy.”

Currently, big tech companies such as Google, Microsoft, and Meta are securing multi-gigawatt solar deals to power their data centers, which are heavily concentrated in the South, Southwest, and Eastern United States. “That will also happen with wind, but not at the same scale,” da Fonseca says. “Annual installations of solar [range from] 20 gigawatts to 40 gigawatts per year, while wind is in the single digits for volume, due to grid constraints and permitting delays. These bottlenecks mean that fossil fuels are still part of the mix, but renewables will definitely play a role in this demand.”

Most sites with high wind speeds were

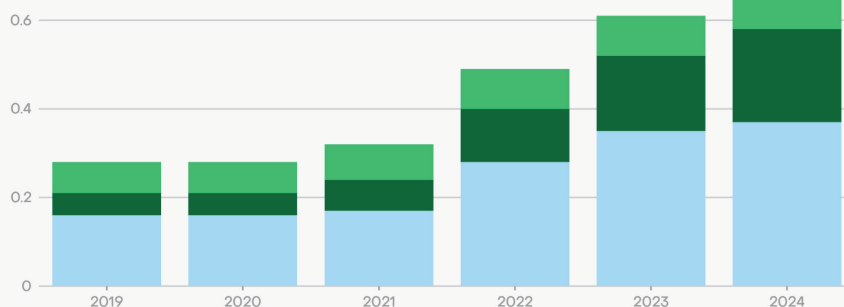
populated many years ago, da Fonseca explains, and with high wind speeds, turbines are more efficient. “Today, we have low-wind-speed sites available,” da Fonseca says. To efficiently capture this energy, original equipment manufacturers (OEMs) are designing larger, low-specific-rating turbines specifically for low-wind-speed sites. “The U.S. is currently installing turbines that generate 2-4 megawatts, but we will see them increasing to 6-7 megawatts by 2029.”

Since the start of the second Trump administration, Wood Mackenzie has cut its U.S. wind power forecast by more than 40%. “On an annual basis, we had something around 8 to 9 gigawatts of wind capacity installations,” da Fonseca says. “Now we are down to between 4 and 6 after 2030, with no certainty on how projects will get permitting or start construction. Offshore wind is very much halted ... except for those already underway.”

Emerging drivers of electricity demand are contributing more than twice as much to demand growth as they were five years ago.

Annual change in global electricity demand (%)

■ Data centers (including crypto mining) ■ EVs ■ Heat pumps



Source: Ember calculations (see Global Electricity Review 2025 – Methodology)

EMBER

The heat beneath our feet

Electricity from geothermal energy has been generated for heating and cooling for more than a century and for therapeutic purposes for millennia. Today, the U.S. has the highest installed capacity, followed by Indonesia and the Philippines. In Iceland, geothermal heated 9 out of 10 homes in 2022. Yet it represents only about 1% of the global energy mix.

“The problem isn’t technology, it’s lack of awareness,” says Vanessa Robertson, director of policy and education for the

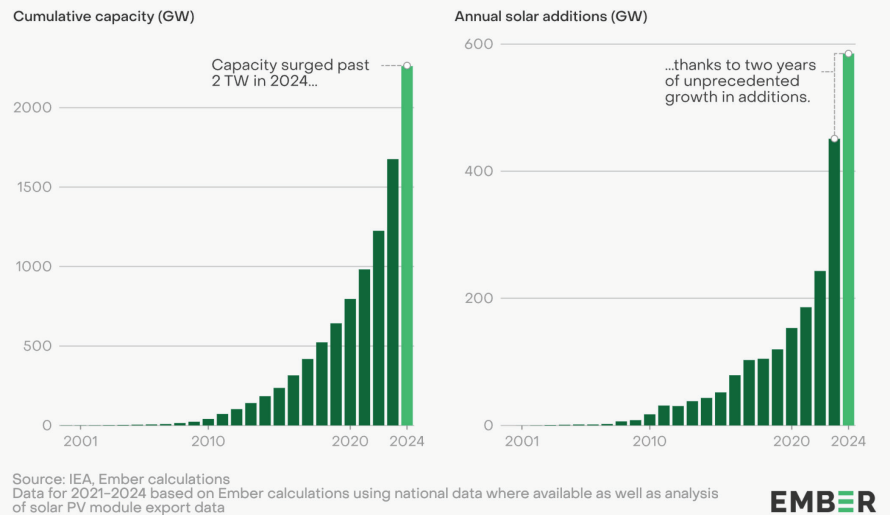
global trade association Geothermal Rising. “Geology and science education is a big barrier that we’re trying to address.”

Geothermal energy is baseload energy — available at all times — in the form of heating, cooling, and electricity generation. And it has the lowest emissions and carbon footprint of any energy source, according to Geothermal Rising. “With 95% of its supply chain made in the U.S., geothermal has incredible potential to help stabilize the grid by offsetting energy sources like solar, wind, and other intermittent technologies,” Robertson says. “And there’s a skilled workforce ready to go that is transitioning from the oil and gas industry.”

Geothermal is also expanding into more diverse geographical locations. “Traditionally, geothermal power plants had to have three things: heat relatively closer to the surface, a water source below the water table, and permeability,” Robertson explains. “Water is injected, seeps through permeable rock, heats up, and is brought to the surface and used to generate electricity. It’s a symbiotic sort of relationship.”

Next-generation technologies fall into two main areas: enhanced geothermal systems, or EGS, and augmented geothermal systems, or AGS. EGS systems drill deep down, horizontally at times, and stimulate fractures to create permeability. AGS systems are closed-loop technologies that drill and inject fluid, which is heated with convection, then brought to the surface without the need for water and fracturing. This

Global solar capacity additions jumped 30% in 2024 – yet another record.



method can be used in arid regions to create the fracture networks that allow fluid to penetrate.

Other technology in development involves drilling faster by using microwave-like lasers that melt rock and create glass-like boreholes, eliminating the cost of manufacturing and installing pipe. Yet another method uses geopressure to create caverns where water is pressurized and then released as needed for dispatchable power. “As a trade association, we’re tech-agnostic and support all geothermal technologies,” Robertson says. “A rising tide lifts all boats.”

Geothermal has enjoyed bipartisan support for decades, but a lack of presence with policymakers has left it

overlooked in many funding decisions, or what Robertson calls a “low profile” among renewables. To gain visibility, Geothermal Rising created a policy council to build those relationships, which has been key to preserving government funding. “Geothermal is still a nascent technology,” Robertson says. “It needs this investment and support to prove that the cost pans out, and investors can rely on that.”

Internationally, Iceland generates 25% of its electricity from geothermal, and Kenya, Indonesia, and Canada will become hotspots for development, according to Robertson. But she expects new technologies will grow fastest in the U.S., then spread to other countries. “With the increase in data center demand for water, energy, and cooling, geothermal is a perfect partner,” she says. “These next-generation technologies can be co-located and hooked up directly, without extensive transmission lines and infrastructure.”

Hydroelectric power adapts

Though solar is projected to surpass hydropower by 2029, hydro still generates the most renewable electricity globally, rebounding from the drought

EMRGY INC.



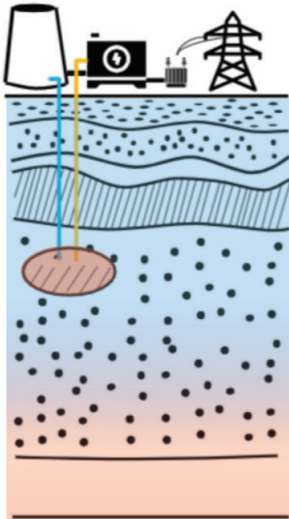
“OUR PLAN, WITH AROUND 1,500 MILES OF CANALS WE ALREADY HAVE UNDER EXCLUSIVITY, IS TO INSTALL 400 MEGAWATTS OF HYDROELECTRIC POWER AND SELL THAT POWER TO THE LOCAL UTILITIES.”

– Emily Morris

CONVENTIONAL AND NEXT-GENERATION GEOTHERMAL TECHNOLOGY

CONVENTIONAL

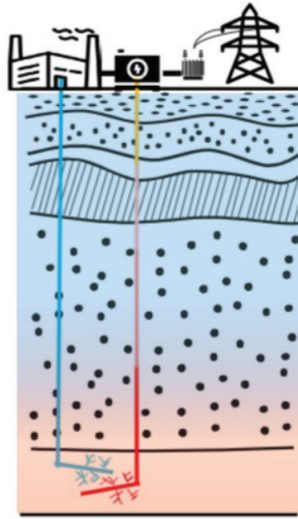
Hydrothermal



- Fluids circulate openly through naturally occurring fractures
- Limited estimated total resource (~40 GW)
- ~4 GW on the grid today

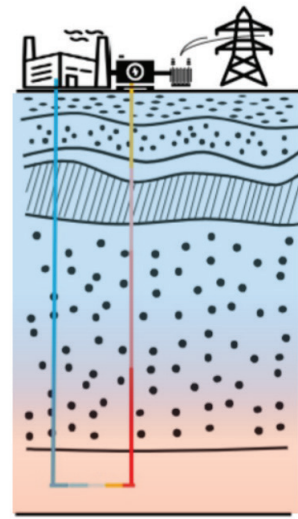
NEXT-GENERATION

Enhanced Geothermal Systems



- Fluids circulate openly within a well pair connected by fractures engineered with hydraulic fracturing and horizontal drilling
- Large estimated total resource (5+ TW for all next-generation geothermal)
- Scales through modular deployment of many well pairs

Closed-Loop Geothermal Systems



- Fluids circulate through a long series of closed wellbore loops permeating the subsurface
- Large estimated total resource (5+ TW all next-generation geothermal)
- Scales through modular deployment and increasing well bore lengths

Source: *Pathways to Commercial Liftoff: Next-Generation Geothermal Power*, Department of Energy, 2024. Executive Summary, Figure 1.

conditions of 2023-24 to an all-time high of 4,416 TWh. China was responsible for 71% of the increased capacity in 2024, followed by Brazil, Canada, and the United States. The downside is hydro-power's susceptibility to drought. Brazil

and Canada saw droughts that lowered their hydro generation in 2024, and the U.S. reached a 20-year low because of its ongoing droughts. Iceland and Norway led in per capita hydro generation.

Though the industry is still domi-

nated by giant dams and vast generation infrastructure, recent technological developments are making use of smaller dams, existing water facilities, and more modular, flexible solutions. "With the growth of renewable energy, we're seeing a lot of new capacity at both the transmission and the distribution level," says Emily Morris, founder and CEO of Emrgy. "Hydropower is a fantastic way to build that. Emrgy's technology is intentionally designed to bring power to the distribution level using water as the feedstock."

Emrgy builds modular hydrokinetic generators that can be installed with a forklift or crane into existing water infrastructure, like canals, water treatment plants, municipal water con-

Nuclear power supplied **9%** of the world's electricity in **2024**, led by **France**, which gets **75%** of its power from **large-scale reactors**. While micronuclear plants are in heavily subsidized development, progress is hampered by expense, safety, and regulatory issues.

veyance systems, industrial inflows and outflows, and thermal power cooling channels. “There are over 150,000 miles of canals in the United States, and over 2 million miles of canals globally, according to the U.N. Food and Agriculture Organization,” says Morris, who received the Society of Women Engineers’ 2025 Entrepreneur Award. “Having a product design that is flexible geographically is something that we’ve spent a lot of time on throughout the design evolution.”

Unlike traditional hydropower with its dams and reservoirs, Emrgy’s technology produces no carbon emissions and is fully portable. “It doesn’t materially affect the water flow,” Morris says. “And

with aging canal infrastructure, Emrgy brings modern technology with data generation that helps irrigators and municipalities use water more efficiently.”

After a successful deployment in the city of Denver in 2017, an irrigation manager and hydrologist in New Zealand came calling. “He was diverting water out of a canal, flowing it through farmland, and then discharging it back, but 30% of the water was lost to seepage beneath eroded canals,” Morris says.

“He installed impermeable liners that not only conserved water, but also made it produce less friction. He either needed to add friction or harvest that energy and convert it into electricity.

“He installed six of our turbines at strategic locations where the canal needed an energy reduction and restored the water flow to baseline by harvesting that energy” Morris says. “That was a really cool engineering achievement. Now, we’re proactively bundling those two solutions.”

Emrgy has exclusivity agreements with water districts that manage more than 10,000 miles of canals in the U.S. West. Its five-year goal is to begin modernizing those canals and adding its hydroelectric platform combined with a water savings platform, Morris says. “Our plan, with around 1,500 miles of canals we already have under exclusivity, is to install 400 megawatts of hydroelectric power and sell that power to the local utilities.”

Three of Emrgy’s current commercial projects are hybridized, meaning the company’s hydro platform acts as baseload generation, with floating solar panels on the downstream side of the turbines adding additional wattage across the linear real estate. Another project includes energy storage to discharge electricity at times of greatest need at the distribution level. Morris believes that “to have a truly renewable, reliable, and secure grid in the future, it is really about making each and every community as resilient as possible.”

Globally, the U.S. ranks second in electricity demand and CO₂ emissions, but outside the top 10 in percentage of electricity generated by renewables. “The overall trend in the global power sector shows that the next few years will be marked by a rapid and increasing build-out of renewables, with solar power at the forefront,” Ember’s report concludes.

“Countries that focus on adapting appropriate policies to take advantage of integrating these low-cost and fast-to-deploy technologies will reap the benefits of the clean energy transition. Those who choose to turn their backs risk being left behind.” ✨

Looking Ahead

New discoveries in renewable technology research and development underscore the need for stable, cohesive energy policies. With support, these early-stage technologies may take an important role in clean energy’s future:

- **Solar.** University of New South Wales researchers have created a novel solar technology that can increase silicon panel efficiency beyond 30% while extending lifespan by operating at cooler temperatures. They discovered that a “singlet fission layer,” which increases the number of electrons harvested by a solar cell, can be integrated with existing silicon technologies without the need for a redesign. Pilot line manufacturing trials are in the works.
- **Wind.** The race is on to engineer taller, bigger, more efficient wind turbines, with Chinese OEM Dongfang Electric Corp. recently announcing a 26 megawatt offering. According to the Global Wind Energy Council’s 2025 report, if current trends continue, turbines with a 350 m (offshore) and 300 m (onshore) rotor diameter and a blade-sweep area of 10 football fields will be manufactured in China by 2030. The incredible size of these turbines presents component, transportation, and installation challenges, but rapid design iteration continues.
- **Hydrogen.** Anita Sengupta, Ph.D., aerospace engineer and founder of Hydroplane, believes that hydrogen-fueled electric propulsion will be in use within general aviation for regional flights in the next five years, while Airbus recently unveiled its four, 2 megawatt-engine, hydrogen fuel cell concept aircraft. And philanthropist and renewable energy pioneer Bertrand Piccard is well into his plan to circumnavigate the globe by 2028 in a zero-emission, green hydrogen-fueled aircraft called Climate Impulse. Liquid hydrogen fuel cells, cooled to -254°C to increase density for greater fuel capacity, will power twin electric motors on the nine-day, nonstop flight. In 2028, Climate Impulse’s developers project it will follow its predecessor, Solar Impulse II, into aviation history.

(Read more about Solar Impulse II in SWE Magazine’s article “Building on the Legacy of Solar Impulse,” a digital exclusive published with the Conference 2021 issue.)