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Climate solutions that can make a difference

By pairing solar power and battery storage, hybrid power plants can keep providing electricity after dark. Petmal via Getty Images

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Introduction

At the Conversation U.S., you'll often read about the damage being caused by climate change. One professor I've worked with calls it the "new abnormal," because there's nothing normal about the severity of the extreme wildfires, heat waves and storms we're seeing today.

But like many crises, climate change is also spurring incredible innovations. Scientists and engineers are working on solutions to lower greenhouse gas emissions from electricity production, transportation, agriculture and other parts of the economy. They're building hybrid solar power plants that keep the lights on long after the sun goes down and finding ways for your car or truck to power your home. They're pulling carbon dioxide out of the air and essentially turning it to stone. We asked several of these innovators to explain the projects and research they're working on. Together they offer a window into some of the technical solutions necessary in the face of climate change.

Stacy Morford
Environment and
Climate Editor

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Meet the power plant of the future: Solar + battery hybrids are poised for explosive growth

By Joachim Seel, Bentham Paulos
and Will Gorman
Lawrence Berkeley National Laboratory

America's electric power system is undergoing radical change as it transitions from fossil fuels to renewable energy. While the first decade of the 2000s saw huge growth in natural gas generation, and the 2010s were the decade of wind and solar, early signs suggest the innovation of the 2020s may be a boom in "hybrid" power plants.

A typical hybrid power plant combines electricity generation with battery storage at the same location. That often means a solar or wind farm paired with large-scale batteries. Working together, solar panels and battery storage can generate renewable power when solar energy is at its peak during the day and then release it as needed after the sun goes down.

A look at the power and storage projects in the development pipeline offers a glimpse of hybrid power's future.

Our team at Lawrence Berkeley National Laboratory found that a staggering 1,400 gigawatts of proposed generation and storage projects have applied to connect to the grid – more than all existing U.S. power plants combined. The largest group is now solar projects, and over a third of those projects involve hybrid solar plus battery storage.

While these power plants of the future offer many benefits, they also raise questions about how the electric grid should best be operated.

Why hybrids are hot

As wind and solar grow, they are starting to have big impacts on the grid.

Solar power already exceeds 25% of annual power generation in California and is spreading rapidly in other states such as Texas, Florida and Georgia. The "wind belt" states, from the Dakotas to Texas, have seen massive deployment of wind turbines, with Iowa now getting a majority of its power from the wind.

This high percentage of renewable power raises a question: How do we integrate renewable sources that produce large but varying amounts of power throughout the day? That's where storage comes in. Lithium-ion battery prices have rapidly fallen as production has scaled up for the electric vehicle market in recent years. While there are concerns about future supply chain challenges, battery design is also likely to evolve.

The combination of solar and batteries allows hybrid plant operators to provide power through the most valuable hours when demand is strongest, such as summer afternoons and evenings when air conditioners are running on high. Batteries also help smooth out production from wind and solar power, store excess power that would otherwise be curtailed, and reduce congestion on the grid.

> ***"While questions remain, it's clear that hybrids are redefining power plants. And they may remake the U.S. power system in the process."***

Hybrids dominate the project pipeline

At the end of 2020, there were 73 solar and 16 wind hybrid projects operating in the U.S., amounting to 2.5 gigawatts of generation and 0.45 gigawatts of storage.

Today, solar and hybrids dominate the development pipeline. By the end of 2021, more than 675 gigawatts of proposed solar plants had applied for grid connection approval, with over a third of them paired with storage. Another 247 gigawatts of wind farms were in line, with 19 gigawatts, or about 8% of those, as hybrids.

Of course, applying for a connection is only one step in developing a power plant. A developer also needs land and community agreements, a sales contract, financing and permits. Only about one in four new plants proposed between 2010 and 2016 made it to commercial operation. But the depth of interest in hybrid plants portends strong growth.

In markets like California, batteries are essentially obligatory for new solar developers. Since solar often accounts for the majority of power in the daytime market, building more adds little value. Currently 95% of all proposed large-scale solar capacity in the California queue comes with batteries.

5 lessons on hybrids and questions for the future

The opportunity for growth in renewable hybrids is clearly large, but it raises some questions that our group at Berkeley Lab has been investigating.

Here are some of our top findings:

- **The investment pays off in many regions.** We found that while adding batteries to a solar power plant increases the price, it also increases the value of the power. Putting generation and storage in the same location can capture benefits from tax credits, construction cost savings and operational flexibility. Looking at the revenue potential over recent years, and with the help of federal tax credits, the added value appears to justify the higher price.

- **Co-location also mean tradeoffs.** Wind and solar perform best where the wind and solar resources are strongest, but batteries provide the most value where they can deliver the greatest grid benefits, like relieving congestion. That means there are trade-offs when determining the best location with the highest value. Federal tax credits that can be earned only when batteries are co-located with solar may be encouraging suboptimal decisions in some cases.

- **There is no one best combination.** The value of a hybrid plant is determined in part by the configuration of the equipment. For example, the size of the battery relative to a solar generator can determine how late into the evening the plant can deliver power. But the value of nighttime power depends on local market conditions, which change throughout the year.

- **Power market rules need to evolve.** Hybrids can participate in the power market as a single unit or as separate entities, with the solar and storage bidding independently. Hybrids can also be either sellers or buyers of power, or both. That can get complicated. Market participation rules for hybrids are still evolving, leaving plant operators to experiment with how they sell their services.

- **Small hybrids create new opportunities:** Hybrid power plants can also be small, such as solar and batteries in a home or business. Such hybrids have become standard in Hawaii as solar power saturates the grid. In California, customers who are subject to power shutoffs to prevent wildfires are increasingly adding storage to their solar systems. These "behind-the-meter" hybrids raise questions about how they should be valued, and how they can contribute to grid operations.

Hybrids are just beginning, but a lot more are on the way. More research is needed on the technologies, market designs and regulations to ensure the grid and grid pricing evolve with them.

While questions remain, it's clear that hybrids are redefining power plants. And they may remake the U.S. power system in the process.

Equinor's Hywind Scotland became the world's first floating wind farm in 2017. Øyvind Gravås/Woldcam via Equinor

California is planning floating wind farms offshore to boost its power supply – here's how they work

By Matthew Lackner
UMass Amherst

Northern California has some of the strongest offshore winds in the U.S., with immense potential to produce clean energy. But it has a problem. Its continental shelf drops off quickly, making building traditional wind turbines directly on the seafloor costly if not impossible.

Once water gets more than about 200 feet deep – roughly the height of an 18-story building – these "monopile" structures are pretty much out of the question.

A solution has emerged that's being tested in several locations around the world: making wind turbines that float. In fact, in California, where drought is putting pressure on the hydropower supply and fires have threatened electricity imports from the Pacific Northwest, the state is moving forward on plans to develop the nation's first floating offshore wind farms as we speak.

So how do they work?

Three main ways to float a turbine

A floating wind turbine works just like other wind turbines – wind pushes on the blades, causing the rotor to turn, which drives a generator that creates electricity. But instead of having its tower embedded directly into the ground or the sea floor, a floating wind turbine sits on a platform with mooring lines, such as chains or ropes, that connect to anchors in the seabed below.

These mooring lines hold the turbine in place against the wind and keep it connected to the cable that sends its electricity back to shore.

Most of the stability is provided by the floating platform itself. The trick is to design the platform so the turbine doesn't tip too far in strong winds or storms.

There are three main types of platforms:

- A spar buoy platform is a long hollow cylinder that extends downwards from the turbine tower. It floats vertically in deep water, weighted with ballast in the bottom of the cylinder to lower its center of gravity. It's then anchored in place, but with slack lines that allow it to move with the water to avoid damage. Spar buoys have been used by the oil and gas industry for years for offshore operations.

- Semi-submersible platforms have large floating hulls that spread out from the tower, also anchored to prevent drifting. Designers have been experimenting with multiple turbines on some of these hulls.

- Tension leg platforms have smaller platforms with taut lines running straight to the floor below. These are lighter but more vulnerable to earthquakes or tsunamis because they rely more on the mooring lines and anchors for stability.

Each platform must support the weight of the turbine and remain stable while the turbine operates. It can do this in part because the hollow platform, often made of large steel or concrete structures, provides buoyancy to support the turbine. Since some can be fully assembled in port and towed out for installation, they might be far cheaper than fixed-bottom structures, which requires specialty boats for installation on site.

Floating platforms can support wind turbines that can produce 10 megawatts or more of power – that's similar in size to other offshore wind turbines and several times larger than the capacity of a typical onshore wind turbine you might see in a field.

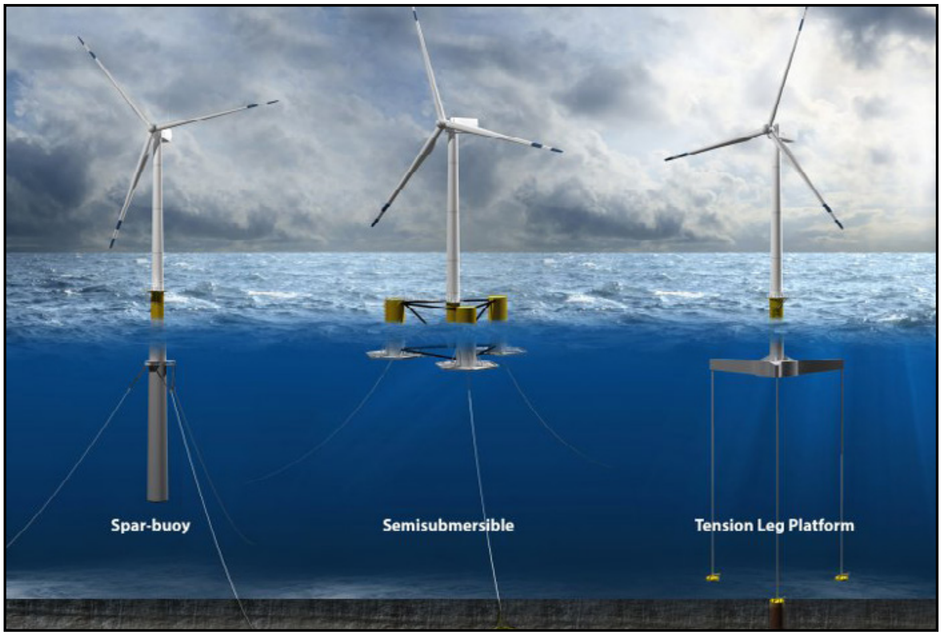
Why do we need floating turbines?

Some of the strongest wind resources are away from shore in locations with hundreds of feet of water below, such as off the U.S. West Coast, the Great Lakes, the Mediterranean Sea, and the coast of Japan.

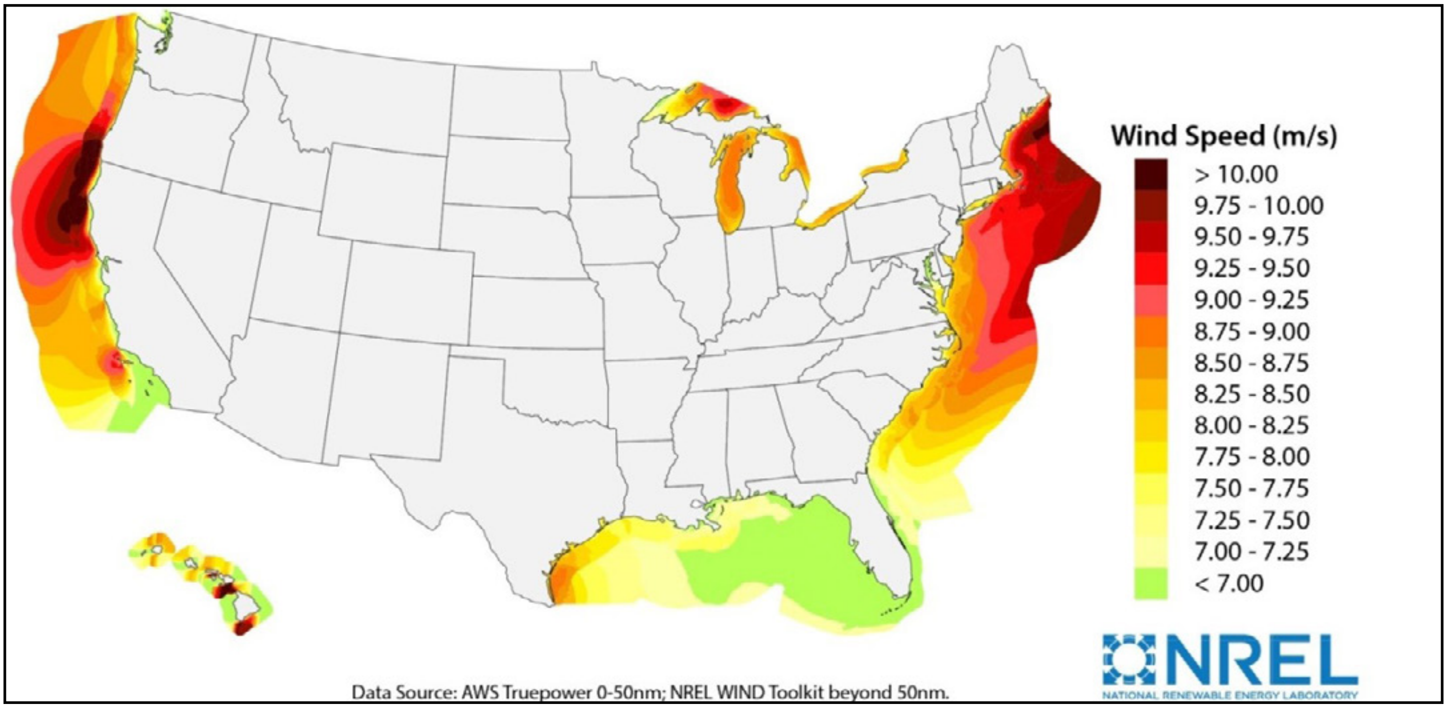
In May 2021, Interior Secretary Deb Haaland and California Gov. Gavin Newsom announced plans to open up parts of the West Coast, off central California's Morro Bay and near the Oregon state line, for offshore wind power. The water there gets deep quickly, so any wind farm that is even a few miles from shore will require floating turbines. Newsom said the area could initially provide 4.6 gigawatts of clean energy, enough to power 1.6 million homes. That's more than 100 times the total U.S. offshore wind power today.

Globally, several full-scale demonstration projects are already operating in Europe and Asia. The Hywind Scotland project became the first commercial-scale offshore floating wind farm in 2017, with five 6-megawatt turbines supported by spar buoys designed by the Norwegian energy company Equinor.

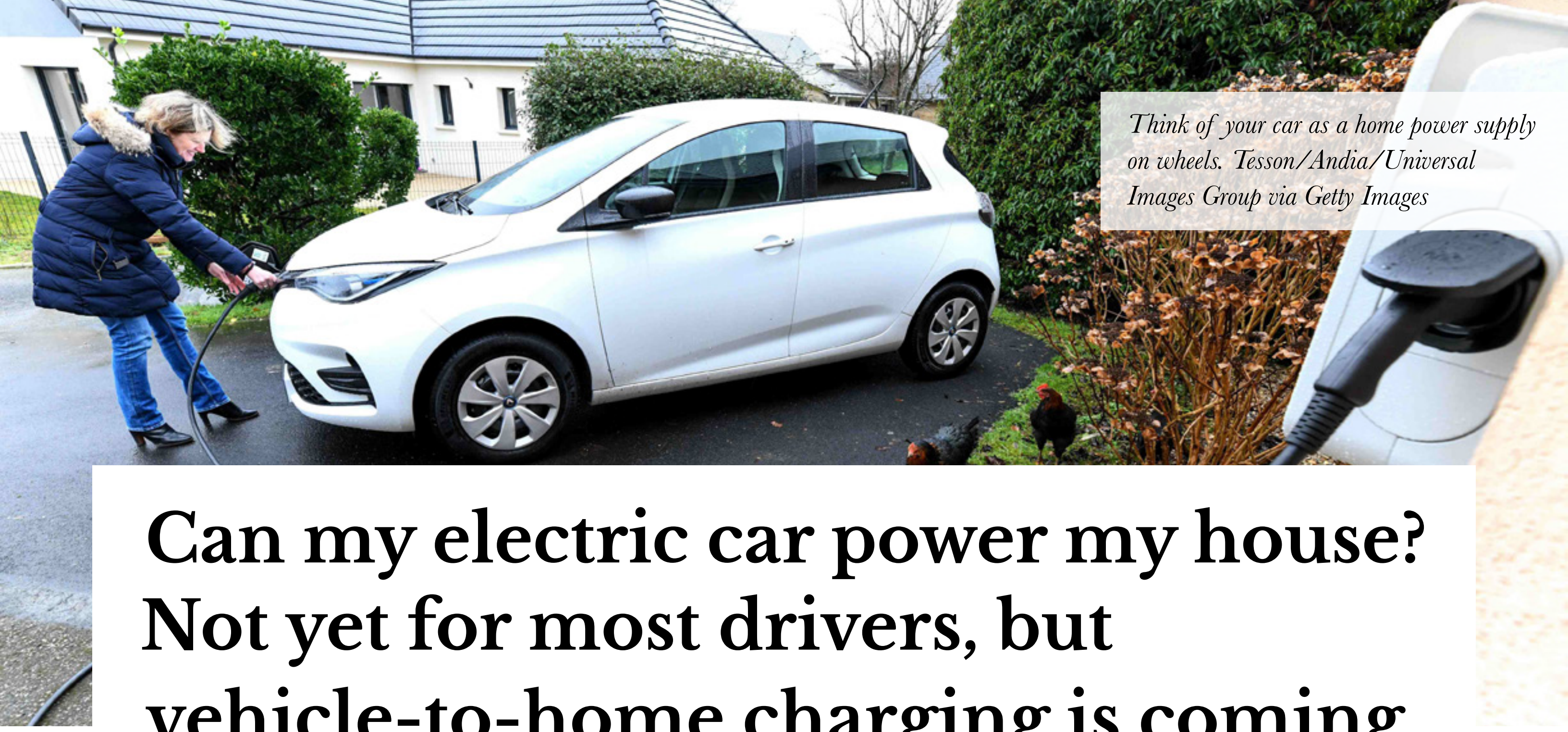
While floating offshore wind farms are becoming a commercial technology, there are still technical challenges that need to be solved. The platform motion may cause higher forces on the blades and tower, and more complicated and unsteady aerodynamics. Also, as water depths get very deep, the cost of the mooring lines, anchors, and electrical cabling may become very high, so cheaper but still reliable technologies will be needed.



Three of the common types of floating wind turbine platform. Josh Bauer/NREL



Some of the strongest offshore wind power potential in the U.S. is in areas where the water is too deep for fixed turbines, including off the West Coast and offshore from Maine. NREL



Think of your car as a home power supply on wheels. Tesson/Andia/Universal Images Group via Getty Images

Can my electric car power my house? Not yet for most drivers, but vehicle-to-home charging is coming

By Seth Blumsack
Penn State

As manufacturers introduce new models of electric vehicles, demand for them is growing steadily. New EV sales in the U.S. roughly doubled in 2021 and could double again in 2022, from 600,000 to 1.2 million. Auto industry leaders expect that EVs could account for at least half of all new U.S. car sales by the end of the decade.

EVs appeal to different customers in different ways. Many buyers want to help protect the environment; others want to save money on gasoline or try out the latest, coolest technology. In areas like California and Texas that have suffered large weather-related power failures in recent years, consumers are starting to consider EVs in a new way: as a potential electricity source when the lights go out. Ford has made backup power a selling point of its electric F-150 Lightning pickup truck, which is due to arrive in showrooms sometime in the spring of 2022. The company says the truck can fully power an average house for three days on a single charge.

So far, though, only a few vehicles can charge a house in this way, and it requires special equipment. Vehicle-to-home charging, or V2H, also poses challenges for utilities. Here are some of the key issues involved in bringing V2H to the mainstream.

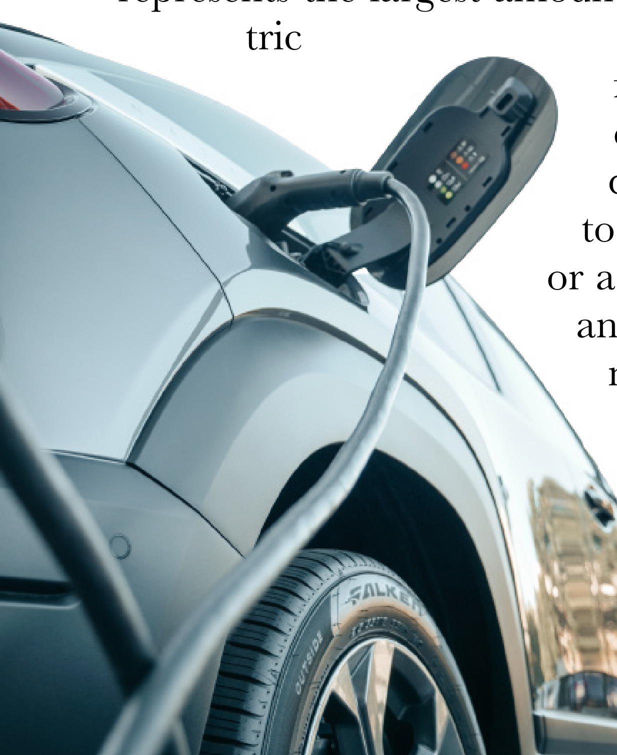
The ABCs of V2H

The biggest factors involved in using an EV to power a home are the size of the vehicles's battery and whether it is set up for "bidirectional charging." Vehicles with this capacity can use electricity to charge their batteries and can send electricity from a charged battery to a house. There are two ways to judge how “big” a battery is. The first is the total amount of electric fuel stored in the battery. This is the most widely publicized number from EV manufacturers, because it determines how far the car can drive.

Batteries for electric sedans like the Tesla Model S or the Nissan Leaf might be able to store 80 to 100 kilowatt-hours of electric fuel. For reference, 1 kilowatt-hour is enough energy to power a typical refrigerator for five hours.

A typical U.S. home uses around 30 kilowatt-hours per day, depending on its size and which appliances people use. This means that a typical EV battery can store enough electric fuel to supply the total energy needs of a typical home for a couple of days.

The other way to assess the capacity of an EV battery is its maximum power output in backup power mode. This represents the largest amount of electric fuel that could be delivered to the grid or a house at any given moment. An EV operating in backup mode will typically have a lower maximum power output than when in driving mode. The backup power capacity is important, because it indicates how many appliances an EV battery could power at once.



This figure is not as widely publicized for all EVs, in part because vehicle-to-home charging hasn’t yet been widely deployed. Ford has advertised that its electric F-150 would have a maximum V2H power output of 2.4 kilowatts, potentially upgradable to 9.6 kilowatts – about the same as a single higher-end Tesla Powerwall home energy storage unit.

On the low end, 2.4 kilowatts is enough power to run eight to 10 refrigerators at the same time and could run much of a typical household continuously for a few days – or much more if the electricity is used sparingly. On the high end, a power level of 9.6 kilowatts could run more appliances or higher-powered ones, but that level of usage would drain the battery faster.

Storing power when it’s cheaper

To draw home power from their cars, EV owners need a bidirectional charger and an electric vehicle that is compatible with V2H. Bidirectional chargers are already commercially available, though some can add several thousand dollars to the price of the car.

A limited number of EVs on the market now are compatible with V2H, including the Ford Lightning, Nissan Leaf and Mitsubishi Outlander. General Motors and Pacific Gas & Electric plan to test V2H charging in California in mid-2022 using multiple GM electric vehicles.

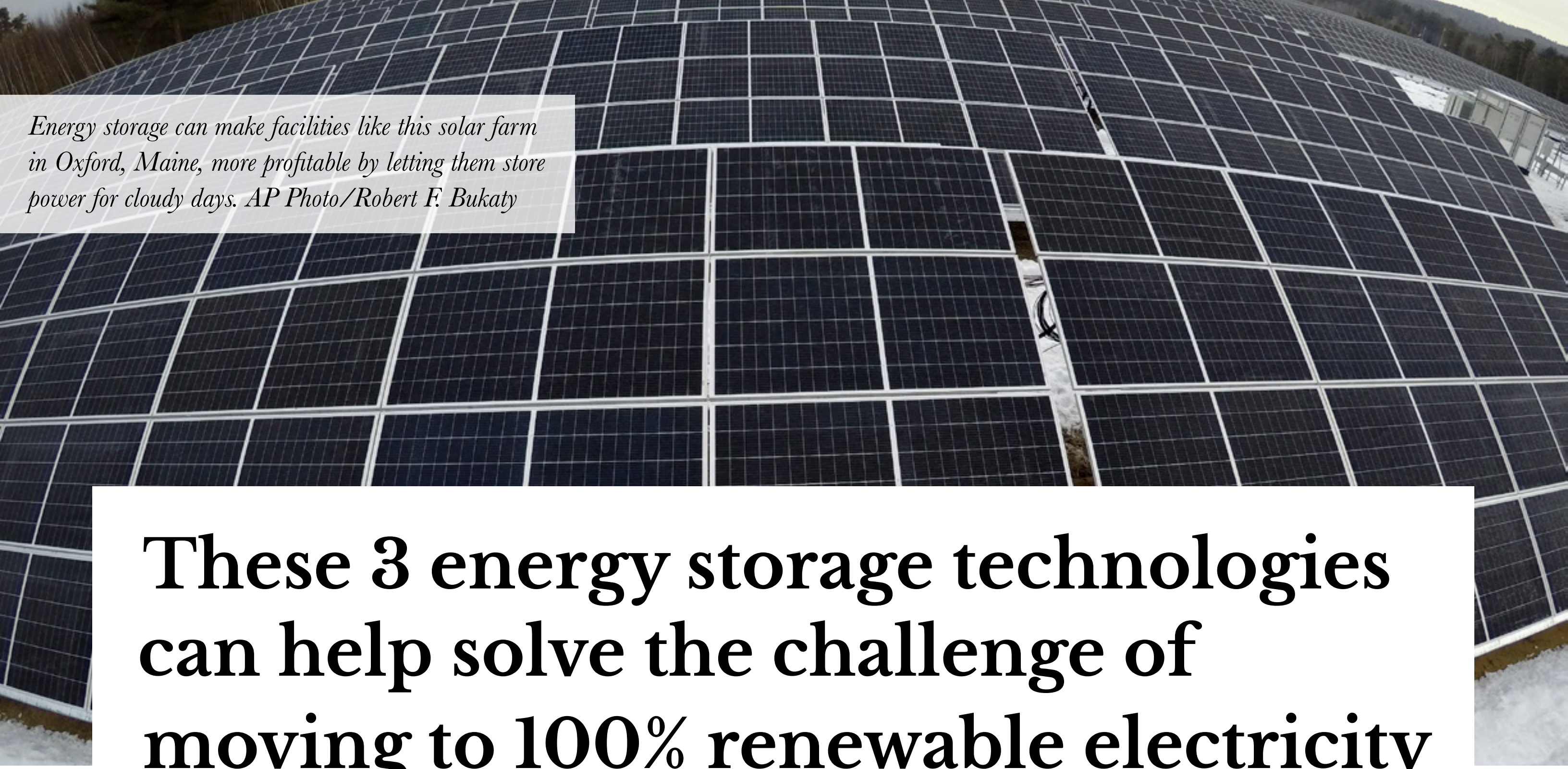
Some homeowners might hope to use their vehicle for what utility planners call "peak shaving" – drawing household power from their EV during the day instead of relying on the grid, thus reducing their electricity purchases during peak demand hours. To do this, they might need to install special metering equipment that can control both the discharging of the vehicle battery and the flow of power from the grid to the home. Peak shaving makes the most sense in areas where utilities have time-of-use electric pricing, which makes power from the grid much more expensive during the day than at night. A peak-shaving household would use cheap electricity at night to charge the EV battery and then store that electricity to use during the day, avoiding high electricity prices.

Utilities and the future of V2H

While V2H capabilities exist now, it will likely be a little while before they see widespread adoption. The market for V2H-compatible electric vehicles will need to grow, and the costs of V2H chargers and other equipment will need to come down. As with Tesla's Powerwall, the biggest market for V2H will probably be homeowners who want backup power for when the grid fails but don't want to invest in a special generator just for that purpose. Enabling homeowners to use their vehicles as backup when the power goes down would reduce the social impacts of large-scale blackouts. It also would give utilities more time to restore service – especially when there is substantial damage to power poles and wires, as occurred during Hurricane Ida in Louisiana in August 2021.

Power companies will still have to spend money building and maintaining the grid to provide reliable service. In some areas, those grid maintenance costs are passed on to customers through peak demand charges, meaning that people without V2H – who will be more likely to have lower incomes – may well bear a greater share of those costs than those with V2H, who will avoid purchasing peak power from the grid. This is especially true if lots of EV owners use rooftop solar panels to charge their car batteries and use those vehicles for peak shaving.

Still, even with V2H, electric vehicles are a huge potential market for electric utilities. Bidirectional charging is also an integral part of a broader vision for a next-generation electric grid in which millions of EVs are constantly taking power from the grid and giving it back – a key element of an electrified future. First, though, energy planners will need to understand how their customers use V2H and how it may affect their strategies for keeping the grid reliable.



Energy storage can make facilities like this solar farm in Oxford, Maine, more profitable by letting them store power for cloudy days. AP Photo/Robert F. Bukaty

These 3 energy storage technologies can help solve the challenge of moving to 100% renewable electricity

By Kerry Rippy
National Renewable Energy Laboratory

In recent decades the cost of wind and solar power generation has dropped dramatically. This is one reason that the U.S. Department of Energy projects that renewable energy will be the fastest-growing U.S. energy source through 2050.

However, it's still relatively expensive to store energy. And since renewable energy generation isn't available all the time – it happens when the wind blows or the sun shines – storage is essential.

As a researcher at the National Renewable Energy Laboratory, I work with the federal government and private industry to develop renewable energy storage technologies. In a recent report, researchers at NREL estimated that the potential exists to increase U.S. renewable energy storage capacity by as much as 3,000% percent by 2050.

Here are three emerging technologies that could help make this happen.

Longer charges

From alkaline batteries for small electronics to lithium-ion batteries for cars and laptops, most people already use batteries in many aspects of their daily lives. But there is still lots of room for growth.

For example, high-capacity batteries with long discharge times – up to 10 hours – could be valuable for storing solar power at night or increasing the range of electric vehicles. Right now there are very few such batteries in use. However, according to recent projections, upwards of 100 gigawatts' worth of these batteries will likely be installed by 2050. For comparison, that's 50 times the generating capacity of Hoover Dam. This could have a major impact on the viability of renewable energy.

One of the biggest obstacles is limited supplies of lithium and cobalt, which currently are essential for making lightweight, powerful batteries. According to some estimates, around 10% of the world's lithium and nearly all of the world's cobalt reserves will be depleted by 2050.

Furthermore, nearly 70% of the world's cobalt is mined in the Congo, under conditions that have long been documented as inhumane.

Scientists are working to develop techniques for recycling lithium and cobalt batteries, and to design batteries based on other materials. Tesla plans to produce cobalt-free batteries within the next few years. Others aim to replace lithium with sodium, which has properties very similar to lithium's but is much more abundant.

Safer batteries

Another priority is to make batteries safer. One area for improvement is electrolytes – the medium, often liquid, that allows an electric charge to flow from the battery's anode, or negative terminal, to the cathode, or positive terminal.

When a battery is in use, charged particles in the electrolyte move around to balance out the charge of the electricity flowing out of the battery. Electrolytes often contain flammable materials. If they leak, the battery can overheat and catch fire or melt.

Scientists are developing solid electrolytes, which would make batteries more robust. It is much harder for particles to move around through solids than through liquids, but encouraging lab-scale results suggest that these batteries could be ready for use in electric vehicles in the coming years, with target dates for commercialization as early as 2026.

While solid-state batteries would be well suited for consumer electronics and electric vehicles, for large-scale energy storage, scientists are pursuing all-liquid designs called flow batteries.

In these devices both the electrolyte and the electrodes are liquids. This allows for super-fast charging and makes it easy to make really big batteries. Currently these systems are very expensive, but research continues to bring down the price.

Storing sunlight as heat

Other renewable energy storage solutions cost less than batteries in some cases. For example, concentrated solar power plants use mirrors to concentrate sunlight, which heats up hundreds or thousands of tons of salt until it melts. This molten salt then is used to drive an electric generator, much as coal or nuclear power is used to heat steam and drive a generator in traditional plants.

These heated materials can also be stored to produce electricity when it is cloudy, or even at night. This approach allows concentrated solar power to work around the clock. This idea could be adapted for use with nonsolar power generation technologies. For example, electricity made with wind power could be used to heat salt for use later when it isn't windy.

Concentrating solar power is still relatively expensive. To compete with other forms of energy generation and storage, it needs to become more efficient. One way to achieve this is to increase the temperature the salt is heated to, enabling more efficient electricity production. Unfortunately, the salts currently in use aren't stable at high temperatures. Researchers are working to develop new salts or other materials that can withstand temperatures as high as 1,300 degrees Fahrenheit (705 C).

One leading idea for how to reach higher temperature involves heating up sand instead of salt, which can withstand the higher temperature. The sand would then be moved with conveyor belts from the heating point to storage. The Department of Energy recently announced funding for a pilot concentrated solar power plant based on this concept.

Advanced renewable fuels

Batteries are useful for short-term energy storage, and concentrated solar power plants could help stabilize the electric grid. However, utilities also need to store a lot of energy for indefinite amounts of time. This is a role for renewable fuels like hydrogen and ammonia. Utilities would store energy in these fuels by producing them with surplus power, when wind turbines and solar panels are generating more electricity than the utilities' customers need.

Hydrogen and ammonia contain more energy per pound than batteries, so they work where batteries don't. For example, they could be used for shipping heavy loads and running heavy equipment, and for rocket fuel.

Today these fuels are mostly made from natural gas or other nonrenewable fossil fuels via extremely inefficient reactions. While we think of it as a green fuel, most hydrogen gas today is made from natural gas.

Scientists are looking for ways to produce hydrogen and other fuels using renewable electricity. For example, it is possible to make hydrogen fuel by splitting water molecules using electricity. The key challenge is optimizing the process to make it efficient and economical. The potential payoff is enormous: inexhaustible, completely renewable energy.

These machines scrub greenhouse gases from the air – an inventor of direct air capture technology shows how it works

By Klaus Lackner
Arizona State University

Two centuries of burning fossil fuels has put more carbon dioxide, a powerful greenhouse gas, into the atmosphere than nature can remove. As that CO2 builds up, it traps excess heat near Earth's surface, causing global warming. There is so much CO2 in the atmosphere now that most scenarios show ending emissions alone won't be enough to stabilize the climate – humanity will also have to remove CO2 from the air.

The U.S. Department of Energy has a new goal to scale up direct air capture, a technology that uses chemical reactions to capture CO2 from air. While federal funding for carbon capture often draws criticism because some people see it as an excuse for fossil fuel use to continue, carbon removal in some form will likely still be necessary, IPCC reports show. Technology to remove carbon mechanically is in development and operating at a very small scale, in part because current methods are prohibitively expensive and energy intensive. But new techniques are being tested this year that could help lower the energy demand and cost.

We asked Arizona State University Professor Klaus Lackner, a pioneer in direct air capture and carbon storage, about the state of the technology and where it's headed.

What is direct carbon removal and why is it considered necessary?

When I got interested in carbon management in the early 1990s, what drove me was the observation that carbon piles up in the environment. It takes nature thousands of years to remove that CO2, and we're on a trajectory toward much higher CO2 concentrations, well beyond anything humans have experienced.

Humanity can't afford to have increasing amounts of excess carbon floating around in the environment, so we have to get it back out.

Not all emissions are from large sources, like power plants or factories, where we can capture CO2 as it comes out. So we need to deal with the other half of emissions – from cars, planes, taking a hot shower while your gas furnace is putting out CO2. That means pulling CO2 out of the air.

Since CO2 mixes quickly in the air, it doesn't matter where in the world the CO2 is removed – the removal has the same impact. So we can place direct air capture technology right where we plan to use or store the CO2.

The method of storage is also important. Storing CO_2 for just 60 years or 100 years isn't good enough. If 100 years from now all that carbon is back in the environment, all we did was take care of ourselves, and our grandkids have to figure it out again. In the meantime, the world's energy consumption is growing at about 2% per year.

"Humanity can't afford to have increasing amounts of excess carbon floating around in the environment, so we have to get it back out."

One of the complaints about direct air capture, in addition to the cost, is that it's energy intensive. Can that energy use be reduced?

Two large energy uses in direct air capture are running fans to draw in air and then heating to extract the CO_2. There are ways to reduce energy demand for both.

For example, we stumbled into a material that attracts CO_2 when it's dry and releases it when wet. We realized we could expose that material to wind and it would load up with CO_2. Then we could make it wet and it would release the CO_2 in a way that requires far less energy than other systems. Adding heat created from renewable energy raises the CO_2 pressure even higher, so we have a CO_2 gas mixed with water vapor from which we can collect pure CO_2.

We can save even more energy if the capture is passive – it isn't necessary to have fans blowing the air around; the air moves on its own.

My lab is creating a method to do this, called mechanical trees. They're tall vertical columns of discs coated with a chemical resin, about 5 feet in diameter, with the discs about 2 inches apart, like a stack of records. As the air blows through, the surfaces of the discs absorb CO_2. After 20 minutes or so, the discs are full, and they sink into a barrel below. We send in water and steam to release the CO_2 into a closed environment, and now we have a low-pressure mixture of water vapor and CO_2. We can recover most of the heat that went into heating up the box, so the amount of energy needed for heating is quite small.

By using moisture, we can avoid about half the energy consumption and use renewable energy for the rest. This does require water and dry air, so it won't be ideal everywhere, but there are also other methods.

Can CO_2 be safely stored long term, and is there enough of that type of storage?

I started working on the concept of mineral sequestration in the 1990s, leading a group at Los Alamos. The world can actually put CO_2 away permanently by taking advantage of the fact that it's an acid and certain rocks are base. When CO_2 reacts with minerals that are rich in calcium, it forms solid carbonates. By mineralizing the CO_2 like this, we can store a nearly unlimited amount of carbon permanently.

For example, there's lots of basalt – volcanic rock – in Iceland that reacts with CO_2 and turns it into solid carbonates within a few months. Iceland could sell certificates of carbon sequestration to the rest of the world because it puts CO_2 away for the rest of the world.

There are also huge underground reservoirs from oil production in the Permian Basin in Texas. There are large saline aquifers. In the North Sea, a kilometer below the ocean floor, the energy company Equinor has been capturing CO_2 from a gas processing plant and storing a million tons of CO_2 a year since 1996, avoiding Norway's tax on CO_2 releases. The amount of underground storage where we can do mineral sequestration is far larger than we will ever need for CO_2. The question is how much can be converted into proven reserve.

We can also use direct air capture to close the carbon loop – meaning CO_2 is reused, captured and reused again to avoid producing more. Right now, people use carbon from fossil fuels to extract energy. You can convert CO_2 to synthetic fuels – gasoline, diesel or kerosene – that have no new carbon in them by mixing the captured CO_2 with green hydrogen created with renewable energy. That fuel can easily ship through existing pipelines and be stored for years, so you can produce heat and electricity in Boston on a winter night using energy that was collected as sunshine in West Texas last summer. A tankful of "synfuel" doesn't cost much, and it's more cost-effective than a battery.

The Department of Energy set a new goal to slash the costs of carbon dioxide removal to US$100 per ton and quickly scale it up within a decade. What has to happen to make that a reality?

DOE is scaring me because they make it sound like the technology is already ready. After neglecting the technology for 30 years, we can't just say there are companies who know how to do it and all we have to do is push it along. We have to assume this is a nascent technology.

Climeworks is the largest company doing direct capture commercially, and it sells CO_2 at around $500 to $1,000 per ton. That's too expensive. On the other hand, at $50 per ton, the world could do it. I think we can get there.

The U.S. consumes about 7 million tons of CO_2 a year in merchant CO_2 – think fizzy drinks, fire extinguishers, grain silos use it to control grain powder, which is an explosion hazard. The average price is $60-$150. So below $100 you have a market. What you really need is a regulatory framework that says we demand CO_2 is put away, and then the market will move from capturing kilotons of CO_2 today to capturing gigatons of CO_2.

Where do you see this technology going in 10 years?
I see a world that abandons fossil fuels, probably gradually, but has a mandate to capture and store all the CO_2 long term.

Our recommendation is when carbon comes out of the ground, it should be matched with an equal removal. If you produce 1 ton of carbon associated with coal, oil or gas, you need to put 1 ton away. It doesn't have to be the same ton, but there has to be a certificate of sequestration that assures it has been put away, and it has to last more than 100 years. If all carbon is certified from the moment it comes out of the ground, it's harder to cheat the system.

A big unknown is how hard industry and society will push to become carbon neutral. It's encouraging to see companies like Microsoft and Stripe buying carbon credits and certificates to remove CO_2 and willing to pay fairly high prices.

New technology can take a decade or two to penetrate, but if the economic pull is there, things can go fast. The first commercial jet was available in 1951. By 1965 they were ubiquitous.

Climeworks, a Swiss company, has 15 plants removing carbon dioxide from the air. Climeworks

A pilot plant near the Salton Sea in California pairs lithium extraction with geothermal energy production. Michael McKibben

How a few geothermal plants could solve America's lithium supply crunch and boost the EV battery industry

By Bryant Jones
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Geothermal energy has long been the forgotten member of the clean energy family, overshadowed by relatively cheap solar and wind power, despite its proven potential. But that may soon change – for an unexpected reason.

Geothermal technologies are on the verge of unlocking vast quantities of lithium from naturally occurring hot brines beneath places like California's Salton Sea, a two-hour drive from San Diego.

Lithium is essential for lithium-ion batteries, which power electric vehicles and energy storage. Demand for these batteries is quickly rising, but the U.S. is currently heavily reliant on lithium imports from other countries – most of the nation's lithium supply comes from Argentina, Chile, Russia and China. The ability to recover critical minerals from geothermal brines in the U.S. could have important implications for energy and mineral security, as well as global supply chains, workforce transitions and geopolitics.

As a geologist who works with geothermal brines and an energy policy scholar, we believe this technology can bolster the nation's critical minerals supply chain at a time when concerns about the supply chain's security are rising.

Enough lithium to far exceed today's US demand

Geothermal power plants use heat from the Earth to generate a constant supply of steam to run turbines that produce electricity. The plants operate by bringing up a complex saline solution located far underground, where it absorbs heat and is enriched with minerals such as lithium, manganese, zinc, potassium and boron.

Geothermal brines are the concentrated liquid left over after heat and steam are extracted at a geothermal plant. In the Salton Sea plants, these brines contain high concentrations – about 30% – of dissolved solids.

If test projects now underway prove that battery-grade lithium can be extracted from these brines cost effectively, 11 existing geothermal plants along the Salton Sea alone could have the potential to produce enough lithium metal to provide about 10 times the current U.S. demand.

Three geothermal operators at the Salton Sea geothermal field are in various stages of designing, constructing and testing pilot plants for direct lithium extraction from the hot brines.

At full production capacity, the 11 existing power plants near the Salton Sea, which currently generate about 432 megawatts of electricity, could also produce about 20,000 metric tons of lithium metal per year. The annual market value of this metal would be over $5 billion at current prices.

Geopolitical risks in the lithium supply chain

Existing lithium supply chains are rife with uncertainties that put mineral security in question for the United States.

Russia's war in Ukraine and competition with China, as well as close ties between Russia and China, underscore the geopolitical implications of the mineral-intensive clean energy transformation.

China is currently the leader in lithium processing and actively procures lithium reserves from other major producers. Chinese state mining operators often own mines in other countries, which produce other vital clean energy minerals like cobalt and nickel.

There is currently one lithium production facility in the U.S. That facility, in Nevada, extracts saline liquid and concentrates the lithium by allowing the water to evaporate in large, shallow ponds. In contrast, the process for extracting lithium while producing geothermal energy returns the water and brines to the earth. Adding another domestic source of lithium could improve energy and mineral security for the United States and its allies.

A lack of policy support

Geothermal power today represents less

than 0.5% of the utility-scale electricity generation in the U.S. One reason it remains a stagnant energy technology in the U.S. is the lack of strong policy support. Preliminary findings from a research study being conducted by one of us indicate that part of the problem is rooted in disagreements among older and newer geothermal companies themselves, including how they talk about geothermal energy's benefits with policymakers, investors, the media and the public.

Geothermal power has the ability to complement solar and wind energy as a baseload power source – it is constant, unlike sunshine and wind – and to provide energy and mineral security. It could also offer a professional bridge for oil, gas and coal employees to transition into the clean energy economy.

The industry could benefit from policies like risk mitigation funds to lessen drilling exploration costs, grant programs to demonstrate innovations, long-term power contracts or tax incentives.

Adding the production of critical metals like lithium, manganese and zinc from geothermal brines could provide geothermal electrical power operators a new competitive advantage and help get geothermal onto the policy agenda.

Geothermal energy gets a boost in California

Trends might be moving in the right direction for geothermal energy producers.

In February, the California Public Utilities Commission adopted a new Preferred System Plan that encourages the state to develop 1,160 megawatts of new geothermal electricity. That's on top of a 2021 decision to procure 1,000 megawatts from zero emissions, renewable, firm generating resources with an 80% capacity factor – which can only be met by geothermal technologies.

The California decisions were primarily meant to complement intermittent renewable energy, like solar and wind, and the retirement of the Diablo Canyon nuclear power plant. They suggest that the era of geothermal as the forgotten renewable energy may be ending.

An artist's rendering of a solar canal.
Robin Raj, Citizen Group & Solar Aquagrid

First solar canal project is a win for water, energy, air and climate in California

By Roger Bales
University of California, Merced

Mounting evidence suggests the western United States is now in its worst megadrought in at least 1,200 years. Groundwater supplies are being overpumped in many places, and the dryness, wildfires and shrinking water supplies are making climate change personal for millions of people.

As an engineer, I have been working with colleagues on a way to both protect water supplies and boost renewable energy to protect the climate. We call it the solar-canal solution, and it's about to be tested in California.

About 4,000 miles of canals transport water to some 35 million Californians and 5.7 million acres of farmland across the state. As we explained in a 2021 study, covering these canals with solar panels would reduce evaporation of precious water – one of California's most critical resources – and help meet the state's renewable energy goals, while also saving money.

The first prototypes in the U.S. for both wide-span and narrow-span canals are now in development in California's Central Valley. Researchers at the University of California, Merced, are involved in the project, and we will be trying to determine how this can become a large-scale solution.

Conserving water and land

California is prone to drought, and water is a constant concern. Now, the changing climate is bringing hotter, drier weather.

Severe droughts over the past 10 to 30 years dried up wells, caused officials to implement water restrictions and fueled massive wildfires.

At the same time, California has ambitious conservation goals. The state has a mandate to reduce groundwater pumping while maintaining reliable supplies to farms, cities, wildlife and ecosystems. As part of a broad climate change initiative, in October 2020 Gov. Gavin Newsom directed the California Natural Resources Agency to spearhead efforts to conserve 30% of land and coastal waters by 2030.

Most of California's rain and snow falls north of Sacramento during the winter, while 80% of its water use occurs in Southern California, mostly in summer. That's why canals snake across the state – it's the largest such system in the world. We estimate that about 1%-2% of the water they carry is lost to evaporation under the hot California sun.

In a 2021 study, we showed that covering all 4,000 miles of California's canals with solar panels would save more than 65 billion gallons of water annually by reducing evaporation. That's enough to irrigate 50,000 acres of farmland or meet the residential water needs of more than 2 million people. By concentrating solar installations on land that is already being used, instead of building them on undeveloped land, this approach would help California meet its sustainable management goals for both water and land resources.

Climate-friendly power

Shading California's canals with solar panels would generate substantial amounts of electricity. Our estimates show that it could provide some 13 gigawatts of renewable energy capacity, which is about half of the new sources the state needs to add to meet its clean electricity goals: 60% from carbon-free sources by 2030 and 100% renewable by 2045.

Installing solar panels over the canals makes both systems more efficient. The solar panels would reduce evaporation from the canals, especially during hot California summers. And because water heats up more slowly than land, the canal water flowing beneath the panels could cool them by 10 F, boosting production of electricity by up to 3%.

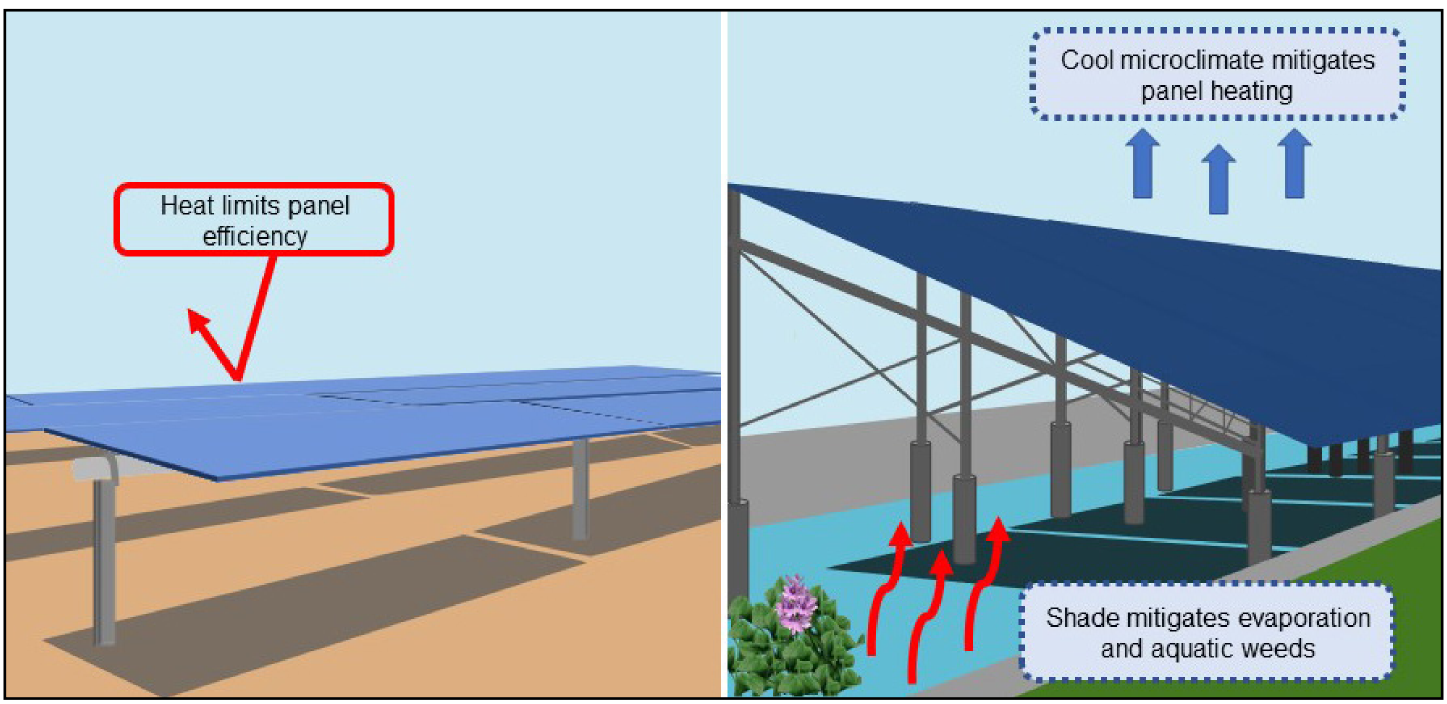
These canopies could also generate electricity locally in many parts of California, lowering both transmission losses and costs for consumers. Combining solar power with battery storage can help build microgrids in rural areas and underserved communities, making the power system more efficient and resilient. This would mitigate the risk of power losses due to extreme weather, human error and wildfires. We estimate that the cost to span canals with solar panels will be higher than building ground-mounted systems. But when we added in some of the co-benefits, such as avoided land costs, water savings, aquatic weed mitigation and enhanced PV efficiency, we found that solar canals were a better investment and provided electricity that cost less over the life of the solar installations. And this is before factoring in the human health benefits of improved air quality and reduced greenhouse gas emissions.

Benefits to the land

To be clear, solar canals are about much more than just generating renewable energy and saving water. Building these long, thin solar arrays could prevent more than 80,000 acres of farmland or natural habitat from being converted for solar farms.

California grows food for an ever-increasing global population and produces more than 50% of the fruits, nuts and vegetables that U.S. consumers eat. However, up to 50% of new renewable energy capacity to meet decarbonization goals could be sited in agricultural areas, including large swaths of prime farmland.

Solar canal installations will also protect wildlife, ecosystems and culturally important land. Large-scale solar developments can result in habitat loss, degradation and fragmentation, which can harm threatened species such as the Mojave Desert tortoise. They also can harm desert-scrub plant communities, including plants that are culturally important to Indigenous tribes. As an example, construction of the Genesis Solar Energy Center in the Sonoran and Mojave deserts in 2012-2014 destroyed trails and burial sites and damaged important cultural artifacts, spurring protracted legal conflict.



Solar panels installed over canals increase the efficiency of both systems. Brandi McKuin, CC BY-ND

Clearing the air – and the weeds
By generating clean electricity, solar canals can improve air quality.

Another benefit is curbing aquatic weeds that choke canals. In India, where developers have been building solar canals since 2014, shade from the panels limits growth of weeds that block drains and restrict water flow. Fighting these weeds is expensive, and herbicides threaten human health and the environment. For large, 100-foot-wide canals in California, we estimate that shading canals would save about US$40,000 per mile. Statewide, savings could reach $69 million per year.

Bringing solar canals to California
California's aging power infrastructure has contributed to catastrophic wildfires and multiday outages. Building smart solar developments on canals and other disturbed land can make power and water infrastructure more resilient while saving water, reducing costs and helping to fight climate change.

Turlock Irrigation District, in California's San Joaquin Valley, will build the first solar canal prototype in partnership with project developer Solar Aquagrid, researchers and others and supported by the state Department of Water Resources.
The prototypes in this mile-long demonstration project, along with future pilots, will help operators, developers and regulators refine designs, assess co-benefits and evaluate how these systems perform. With more data, we can map out strategies for extending solar canals statewide, and potentially across the West.

Climate-friendly farming strategies can improve the land and generate income for farmers

By Lisa Schulte Moore
Iowa State University

Agriculture has not been a central part of U.S. climate policy in the past, even though climate change is altering weather patterns that farmers rely on. Now, however, President Biden has directed the U.S. Department of Agriculture (USDA) to develop a climate-smart agriculture and forestry strategy.

As a scientist focusing on agricultural land use and adviser to several farm organizations, I have the privilege of working alongside farmers who have figured out how to do just that. I am enthusiastic about farmer-led solutions to climate change. What does this look like?

Restore strips of native plants around farm fields

Plants remove carbon from the atmosphere as they grow, and soil can soak up carbon and store it. These abilities are key to climate solutions that crop farmers can readily deploy today.

Seeding narrow strips of land within and around crop fields with native plants is an effective and affordable way to make farming more climate-friendly. Iowa State University's STRIPS Project has shown that this technique reduces erosion and nutrient loss from soil and supports birds and insects.

Prairie strips can reduce emissions of nitrous oxide, a greenhouse gas 298 times more potent than carbon dioxide. Nitrous oxide emissions vary widely across agricultural landscapes and over time, but the largest contributions are associated with poorly drained croplands.

Nitrous oxide forms under anaerobic conditions – environments without oxygen, such as low-lying wet areas of farm fields, where it is produced by soil microbes. The easiest way to keep it from forming is to avoid fertilizing these areas, which amounts to feeding the microbes.

Prairie strips help reduce nitrous oxide emissions by soaking up nitrogen fertilizer that runs off of adjacent cropland. They also can store carbon in soil in two ways: by trapping sediment moving down slopes, and by removing carbon dioxide from the atmosphere through photosynthesis and storing this carbon in plant roots and soil.

Prairie strips are among the least expensive conservation practices available to farmers. This is especially true if the land they occupy is enrolled in the Conservation Reserve Program, which pays farmers to take environmentally sensitive land out of production and conserve it for other purposes.

Installing prairie strips has qualified for Conservation Reserve Program funding since 2019. Colleagues and I estimate that via this route, they cost US$8 yearly per acre of cropland treated. A recent survey found that about half of Iowa farmers were willing to install prairie strips if they could access federal funds.

On April 21, 2021, Agriculture Secretary Tom Vilsack announced that the agency will expand Conservation Reserve Program enrollment and offer higher payment rates for participating. The department is also creating a new Climate-Smart Practice Incentive to promote strategies that sequester carbon and reduce greenhouse gas emissions. I hope this measure will promote national awareness of prairie strips, which today are known mainly in Iowa and neighboring states.

Turn soggy spots into wetlands

Since nitrous oxide emissions come mainly from wet zones, letting these areas remain as wetlands is another climate-smart strategy. Soggy areas tend to yield poorly in most years, and farmers rarely recoup their investment in cropping them. However, wetlands can be troublesome to farm around, which is why many farmers try to drain and farm through them.

But healthy wetlands also provide benefits: They sequester carbon, store and filter water and provide crucial habitat for mammals, birds, frogs and other organisms. The Agriculture Department's new Climate-Smart Practice Incentive will support wetland restoration on agricultural lands.

Another USDA initiative, the Farmable Wetland Program, pays farmers to take previously farmed wetlands and buffer areas out of production for 10 or more years. Enrollment is currently capped at 1 million acres. A climate-smart agricultural policy could expand the program by removing the acreage cap and boosting incentive payments.

Promote perennial crops, especially grasses

All crops are not equal when it comes to mitigating climate change and conserving the environment. Perennials – including various types of grasses, shrubs and trees – provide more ecological benefits than annual crops like corn, wheat and soybeans. But they receive less government support.

Just like annual garden plants, annual crops must be replanted every year. Perennial crops live for multiple seasons, so raising them requires fewer climate-warming inputs, such as fertilizer and fuel to power tractors. These crops develop deep roots that soak up water in soggy spots and help stabilize soil on sloping land.

Many fruits, vegetables and forage crops are perennials. Examples include apples, alfalfa, grapes and asparagus. Researchers are working to develop perennial versions of grains, legumes and oilseeds such as sunflowers.

There are many opportunities to expand cultivation of perennial crops. Grasses and forbs – flowering plants with stems and leaves, such as bee balm – are less expensive to establish and grow than woody crops like willow, and offer farmers more management flexibility.

I direct a transdisciplinary team called C-CHANGE, funded by USDA, that is working with farmers to create and expand market-based value chains for perennial grasses. We are helping farmers plant mixtures of native perennial grasses and forbs to build soil health where it has been eroded and protect environmentally sensitive areas.

The grasses can ultimately be harvested and processed in biodigesters – devices that break down organic materials to produce energy – along with manure or food waste.

This cycle will yield electricity or biomethane from renewable sources that can displace fossil-based energy sources on or off of farms. It also will produce liquid and solid materials that can be used as organic fertilizers, along with other valuable products.

Replacing fertilizer made from synthetic nitrogen is important for the climate because making it consumes enormous quantities of natural gas and releases methane into the atmosphere. Methane is another powerful greenhouse gas, 25 times more potent than carbon dioxide.

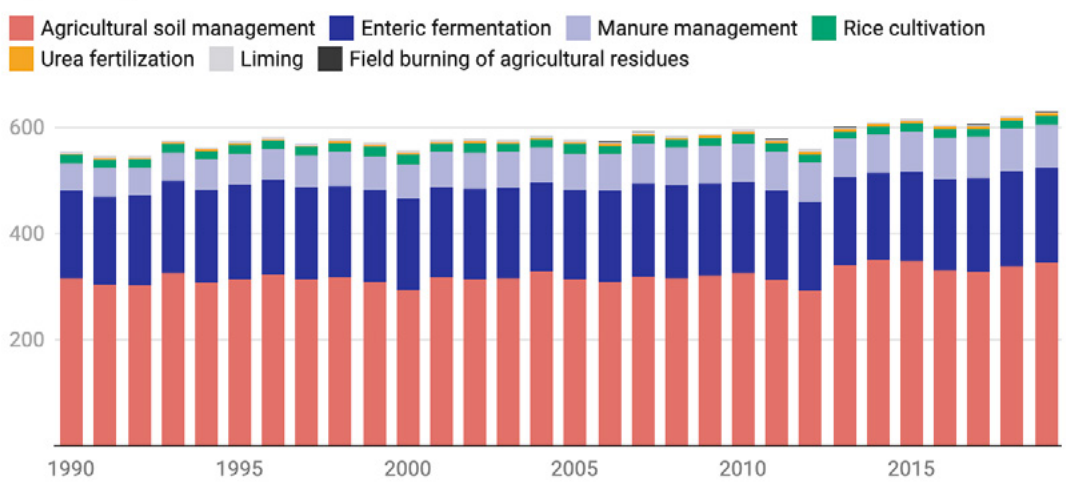
Biodigestion is widely used in Europe but underdeveloped in the U.S. We expect that the value chain we're creating will embed it in a larger cycle that creates a market for protective perennial crops, reduces fossil fuel use and returns carbon to the soil.

The Agriculture Department's Rural Energy for America Program provides grants and loans that can be used to support biodigester construction on farms. Expanding this program, which currently is funded at $50 million yearly through 2022, and making biodigesters a priority, is another climate-friendly opportunity.

When I think of climate-smart agriculture, I picture farmlands with lots of perennial vegetation smartly integrated as prairie strips, wetlands and crops. Federal policies and programs that can make such landscapes a reality are already in place. With concerted efforts and investments, they could be expanded to achieve a pace and scale that will help address climate change.

Most US agricultural greenhouse gas emissions come from soils and livestock

Agriculture accounts for 10% of total U.S. greenhouse gas emissions – an amount nearly equal to South Korea's total national emissions in 2019. Enteric fermentation emissions come from the digestive systems of cows and other ruminant animals.



Million metric tons CO2 equivalent

Chart: The Conversation, CC BY-ND • Source: EPA • Get the data

A road crew paints a street in Los Angeles with coating designed to reduce heat. John McCoy/MediaNews Group/Los Angeles Daily News via Getty Images

Lighter pavement really does cool cities when it's done right

By Lisa Schulte Moore
Iowa State University

When heat waves hit, people start looking for anything that might lower the temperature. One solution is right beneath our feet: pavement.

Think about how hot the soles of your shoes can get when you're walking on dark pavement or asphalt. A hot street isn't just hot to touch – it also raises the surrounding air temperature.

Research shows that building lighter-colored, more reflective roads has the potential to lower air temperatures by more than 2.5 degrees Fahrenheit (1.4 C) and, in the process, reduce the frequency of heat waves by 41% across U.S. cities. But reflective surfaces have to be used strategically – the wrong placement can actually heat up nearby buildings instead of cooling things down.

As researchers in MIT's Concrete Sustainability Hub, we have been modeling these surfaces and determining the right balance for lowering the heat and helping cities reduce their greenhouse gas emissions. Here's how reflective pavement works and what cities need to think about.

Why surfaces heat up

All surfaces, depending on the amount of radiation they absorb or reflect, can affect air temperatures in cities.

In urban areas, about 40% of the land is paved, and that pavement absorbs solar radiation. The absorbed heat in the pavement mass is released gradually, warming the surrounding environment. This can exacerbate urban heat islands and worsen the effects of heat waves. It's part of the reason cities are regularly a few degrees warmer in summer than nearby rural areas and leafy suburbs.

Reflective materials on pavement can prevent that heat from building up and help counteract climate change by reflecting solar radiation back to the top of the atmosphere. White roofs can have the same effect.

To estimate a pavement's reflectivity, we use a measure called albedo. Albedo refers to the proportion of light reflected by a surface. The lower a surface's albedo, the more light it absorbs and, consequentially, the more heat it traps.

"Reflective materials on pavement can prevent that heat from building up and help counteract climate change by reflecting solar radiation back to the top of the atmosphere. White roofs can have the same effect."

Typically, the darker the surface, the lower the albedo. Conventional pavements such as asphalt have a low albedo of around 0.05-0.1, meaning they reflect only 5% to 10% of the light they receive and absorb as much as 95%.

When pavements instead use brighter additives, reflective aggregates, light-reflective surface coatings or lighter paving materials like concrete, they can triple the albedo, sending more radiation back into space.

Though the benefits of reflective pavements can vary across the nation's 4 million miles of roads, they are, on the whole, immense. An MIT CSHub model estimated that an increase in pavement albedo on all U.S. roads could lower energy use for cooling and reduce greenhouse gas emissions equivalent to 4 million cars driven for one year. And when materials are locally sourced, such as light-colored binders or aggregates, the crushed stone, gravel or other hard materials in concrete, these roads can also save money.

Location matters

But not all paved areas are ideal for cool roads. Within cities, and even within urban neighborhoods, the benefits differ.

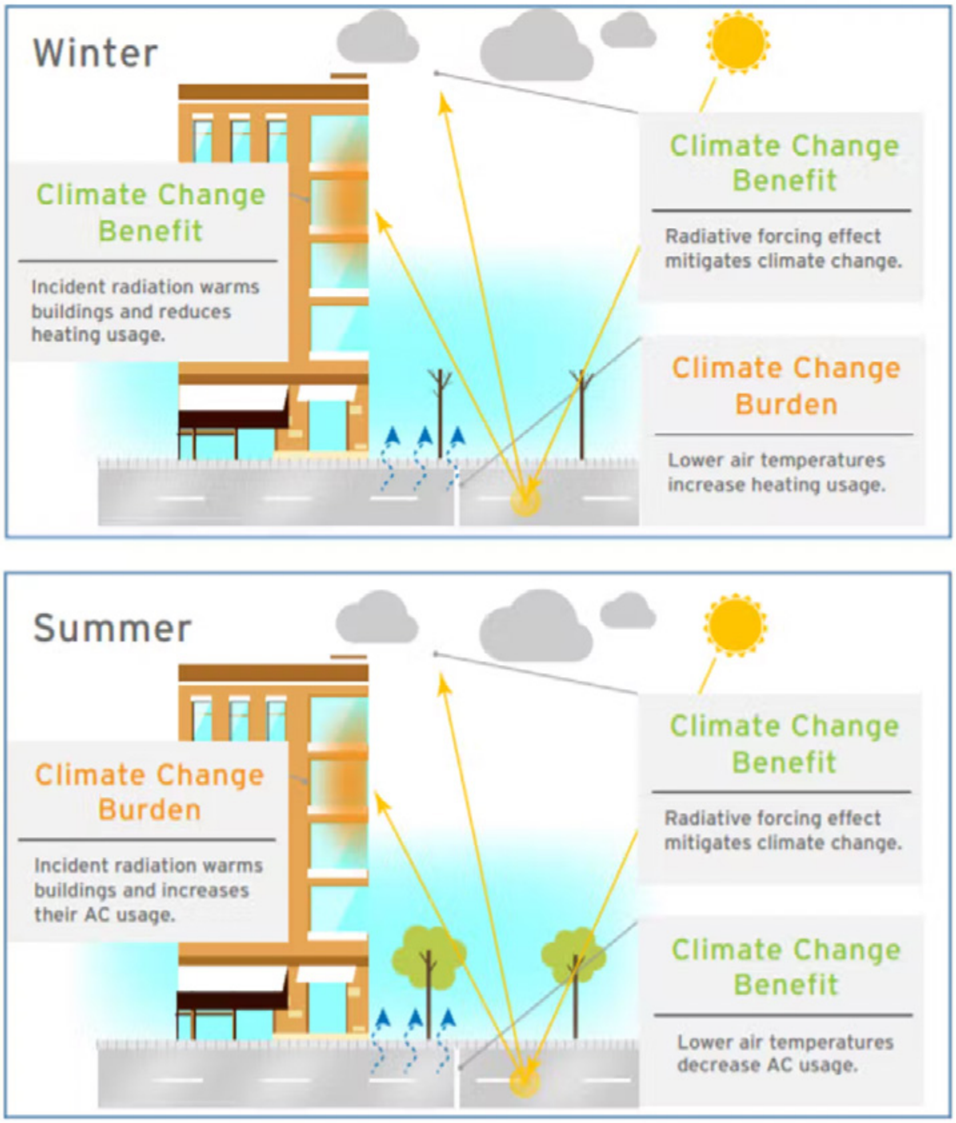
When brighter pavements reflect radiation onto buildings – called incident radiation – they can warm nearby buildings in the summer, actually increasing the demand for air conditioning. That's why attention to location matters.

Consider the differences between Boston and Phoenix.

Boston's dense downtown of narrow streets has tall buildings that block light from directly hitting the pavement most hours of the day. Reflective pavement won't help or harm much there. But Boston's unobstructed freeways and its suburbs would see a net benefit from reflecting a large fraction of incoming sunlight to the top of the atmosphere. Using models, we found that doubling the traditional albedo of the city's roads could cut peak summer temperatures by 1 to 2.7 F (0.3 to 1.7 C).

Phoenix could reduce its summer temperatures even more – by 2.5 to 3.6 F (1.4 to 2.1 C) – but the effects in some parts of its downtown are complicated. In a few low, sparse downtown neighborhoods, we found that reflective pavement could raise the demand for cooling because of increased incident radiation on the buildings.

In Los Angeles, where the city has been experimenting with a cooler coating over asphalt, researchers found another effect to consider. When the coating was used in areas where people walk, the ground itself was as much as 11 F (6.1 C) cooler, but a few feet off the ground, the temperature rose as the sun's rays were reflected. The results suggest such coatings might be better for roads than for sidewalks or playgrounds.



Reflective roads can have different effects in summer and winter depending on the surrounding buildings. MIT

An elegant solution, if used with care

Cities will need to consider all of these effects.

Reflective pavements are an elegant solution that can transform something we use every day to reduce urban warming. The full lifecycle emissions of roads, including the materials used in them, have to be factored in. But as cities consider ways to combat the effects of climate change, we believe strategically optimizing pavement is a smart option that can make urban cores more livable.