Energy

We must change how we harvest, store, and fundamentally think about energy to decrease greenhouse gases. Advancements in renewable energy coupled with updates to our power grids are key. Some of these changes are dependent on government action, but others are being adopted by industry leaders who refuse to wait for regulations to catch up.

As renewables become a greater part of our energy markets, AI is learning to help regulate power loads to ensure grid stability. New energy storage technologies are coming online to counteract the inconstant nature of many renewable sources like solar and wind power. Advances in other low- or no-carbon options like nuclear, hydro, and geothermal energies are providing additional stability. Industries that can't rely on traditional renewables are experimenting with hydrogen and other sustainable fuels.

Recent innovations have made many of these technologies more available and affordable. Widespread adoption may not happen for years, but trials and proofs-of-concept today are proving the potential of green energy.

Upgrading the power grid

Power grids in the US need an overhaul to be able to handle the climate challenges of today, not to mention the demands of the shift to renewables. Catastrophic failures caused in 2021 by winter storms and hurricanes in Texas and Louisiana, respectively, highlighted the weaknesses of power grids in the US.

Infrastructure upgrades must include durable gear and the capacity to handle renewables and distributed grids. Every utility must be prepared to generate and integrate more renewable energy sources. This means closing the gaps filled by coal and gas, which kick online when solar or wind generation drops below the amount needed to sustain a grid.

Automated, networked communications paired with AI can track grid conditions to the second and learn how to spot upcoming spikes in demand and/or drops in supply. These tools can be used for everything from smart pricing adjustments to alerts that prompt connected buildings to decrease energy usage. When used with a distributed grid — where homes and businesses contribute to energy generation (solar panels) and storage (EV batteries) — grid management software reduces the need for polluting energy sources.

AI-powered grid management software Reactive Technologies offers a real-time service to measure grid inertia and system strength, two determinants of how well a grid can respond to disruptions. The company announced its largest-yet funding round of $15M in 2021 and plans to start expanding beyond its roots in the UK and Finland.

Distributed energy company Leap raised $33.5M in Series B funding and announced a partnership with GridPoint to develop virtual power plants (VPPs). Leap enables the growth of distributed grids by making it easy for companies and individuals to earn revenue through selling power back to the grid.

Firm, dispatchable, low-carbon resources

Energy grids in the US rely on firm, dispatchable power to run. That means sources that are reliable and sustained ("firm") and available at any time ("dispatchable"). Many renewables come up short in both areas because they rely on inconstant (and uncontrollable) environmental conditions. Others have suffered from a lack of investment and innovation.

With fresh funding and new technologies, companies are revisiting multiple forms of low- or no-carbon renewable energy that meet both requirements.

Nuclear

The nuclear reactors of tomorrow are safer, smaller, and able to blend into urban environments or scale down to serve small towns.

The public has been wary about nuclear power after the disasters at Chernobyl and Fukushima. Newer nuclear models have almost no risk of meltdown. Nuclear power works best at extremely high temperatures beyond the boiling point of water, so water coolants must be pressurized to remain liquid. A loss of pressure leads to a rapid liquid-to-gas transition, which is what happened at Chernobyl. But gas-cooled fast reactors (GFRs), by nature, cannot experience the rapid expansion that happens during such a phase change.

Molten salt reactors (MSRs) likewise address the risk of explosion with a coolant, typically a mixture of lithium and beryllium fluoride, that is more likely to solidify if disrupted. Beryllium fluoride boils at 1,175°C (over 2,100°F), and lithium boils at 1,336°C (over 2,400°F). The material would be kept at around 700°C (almost 1,300°F) in an operative reactor. MSR design includes an automatic shutdown triggered by the expansion of overheating molten salt.

Preventing the uranium fuel from melting is another way to avoid a nuclear disaster. The Idaho National Laboratory (INL) designed a new type of fuel they call triso, short for tristructural isotropic. The fuel itself is a mixture of uranium and oxygen, but the important part is its coating: layers of graphite and silicon carbide. Triso fuel can safely operate in temperatures up to 1,760°C (3,200°F), which is about 700°C (almost 1,300°F) hotter than the operating temperatures of new reactors. Newer reactor designs shut down if they exceed their safe temperature range. Automatic shut-off plus heat-resistant fuel means there's no chance of a meltdown.

Small modular reactors

Downsizing nuclear reactors means lower costs, more flexibility regarding placement, and easy scalability. Small reactors (300 MW or less) and microreactors (1–20 MW) are possible thanks to the mitigation of meltdown risks. Without the need for large containment structures, new locations become viable for reactors. The risk of nuclear catastrophe can never fully be erased, but smaller reactors mean less fuel and less chance of serious environmental harm.

Smaller reactors are also modular: Individual units are assembled in factories and transported across the country for installation. A utility company (or another customer) can install as many modules as necessary to meet their power needs. Compared to conventional reactors, which often have custom designs and must be constructed on-site, modular reactors are quicker and cheaper to bring online.

The most compact nuclear reactor on the market is NuScale's small modular reactor (SMR) offering, the smallest light-water reactor on the market. The NuScale Power Module itself is 9 feet in diameter and 65 feet wide; a slightly larger containment vessel houses it and a steam generator. The module submerges in a pool for backup heat control. One unit supplies around 77 MW of power, and the nuclear control room can control up to 12 units at once. NuScale closed out its A5 round of investments with $152M.

Nuclear fusion

Traditional nuclear power is fission-based. Now, scientists are closer to recreating nuclear fusion, the process that powers stars. Fission is powerful, but fusion creates 4 times as much energy with the same mass of fuel. Uranium (used in fission) is rare and must be enriched before it can serve as fuel. Fusion uses two isotopes of hydrogen. One of them, deuterium, is found in seawater. The other, tritium, can be made in a fusion reactor with the help of lithium.

The National Ignition Facility, part of California's Lawrence Livermore National Laboratory, is a national leader in nuclear fusion research. Scientists there are attempting to spark fusion using one of the world's largest lasers. Nuclear fusion releases particles and heat, which, at a critical mass, become self-sustaining.

One experiment in 2021 released 1,500 terawatts of power. That's 4 to 5 times more than the entire world uses at a single moment. The NIF team could not replicate the result in further attempts, but the sheer amount of energy created in such a short time shows fusion's great promise.

Hydro

The next century's expansion of hydropower is set to be more environmentally friendly than big dams. In fact, it may not touch our rivers and streams at all.

The last few years have brought multiple advancements in tidal power. Tides may not be uniform, but they are steady and predictable. Underwater turbines placed in the right areas can provide a steady source of power.

These turbines are attached to vessels of the approximate size and shape of a Boeing 747 and anchored in a place where tidal powers are high. The rotors, attached to arms that can raise up to water level for maintenance, generate power no matter what direction they are spinning.

That's how Orbital Marine Power, which raised £7M ($8.9M) through equity crowdfunding, does it. The Orbital O2 in Scottish waters can produce up to 2 MW. It's also the preferred method for Spanish company Magallanes Renovables. Its second-generation ATIR can also generate 2 MW.

In-conduit hydropower is on the other side of the size scale. Micro-hydro setups work within our water systems. Many cities have a gravity-fed water system, which means water flows downhill from its source. Utilities need to slow that water down. In-pipe turbine systems can do the job press-release valves were once needed for and generate energy at the same time.

Micro-hydro setups harness up to 10 MW of electricity depending on their scope. Portland's LucidPipes program powers about 150 homes, a small percentage of the city's residences. San Diego's in-conduit system generates 4.5 MW of power, which is enough for around 5,000 homes.

Offshore wind

Wind farms can take advantage of ocean weather patterns with offshore turbines. It's difficult to construct in the ocean, but the only competitors for real estate are other utilities hoping to build in the area.

Multiple European coastal nations have been using offshore wind farms for years. The US just approved the first major offshore wind farm for the East Coast in 2021. Vineyard Wind will generate 800 MW of electricity. If joined by other proposed projects, the East Coast could add 25 GW of clean energy capacity within a few years.

Offshore wind farms are expensive to construct, and the turbines slated for use in Vineyard Wind aren't the most efficient possibility. They require shallow waters because their foundations are sunk into the ocean floor. The stronger, more constant winds further out to sea would be better for power generation.

Scotland launched the first floating offshore wind farm in 2017 to take advantage of these wind conditions. Floating platforms holding wind turbines are connected to the ocean floor with flexible anchors. Through careful engineering, they stay above the surface and upright even on stormy seas. These turbines are also easier to install, though they require more maintenance.

Equinor, a Norwegian company, provided its Hywind turbines to Scotland and is involved in a number of other offshore wind projects. Its newest concept is a partially submersible turbine that can be constructed on-site.

Geothermal

Geothermal power is available almost anywhere with the help of techniques originally developed to extract oil from shale. Previous initiatives regarding geothermal centered on places with hot springs and geysers — sure signs there's plenty of power to be harvested. Magma may be closer to the surface in such places, but its heat is always accessible if you dig deep enough.

Think tank ClearPath believes the US could get 20% of its power from geothermal electricity within 30 years. A new approach, called enhanced or engineered geothermal systems (EGS), makes it easy to tap power regardless of location.

We have the technology to create underground reservoirs and ways to access them. The oil fracking industry has taught us how to fracture rocks underground by using high-pressure water-and-chemical blasts. EGS uses the same techniques with fluids that won't contaminate underground water supplies. The water, once injected, is allowed to circulate underground so it can heat up before being pumped back up to the surface to generate electricity. The cooled fluid could then be sent into the ground again in a self-sustaining system.

Keeping the fluid in the system is the next big concern EGS innovators must tackle. Texas-based Fervo is researching and testing ways to reduce water loss. The company wrapped up its $28M Series B in 2021 and also finalized a partnership with Google to create a new geothermal plant to power its Nevada data centers.

Sustainable fuels

Sustainable fuels are already de-carbonizing industries and applications that need more power than most renewables and traditional energy storage methods can offer. Transportation, shipping, and manufacturing, among others, require more energy density than batteries allow. Businesses in these sectors typically rely on gasoline, and their best option for sustainability is non-gas-based liquid fuels.

Sustainable aviation fuel

Agricultural biomass, plant-based oils, greases and fats, alcohols, sugars, and waste byproducts have all been used to produce sustainable fuels. Refining methods rely on chemical catalysts and heat, which means the process has the potential to generate a high amount of carbon. Many refining companies choose locations near wind and solar farms to ensure a de-carbonized source of power. The makers of sustainable aviation fuel (SAF) are required to track carbon emissions throughout the process and sell fuel that comes with a certified carbon footprint measurement.

Twelve, a company that turns CO_2 into everything from sunglass lenses to auto parts, partnered with the Air Force for a test of its E-Jet fuel. This carbon-neutral solution is a drop-in fuel, meaning it works with existing planes just like traditional jet fuel would. The company raised $57M in its 2021 Series A funding round and is currently taking orders for E-Jet.

Hydrogen

Hydrogen fuel is another candidate to help de-carbonize sectors that need high energy density. It can be high-, low-, or no-carbon, depending on the production process. Most hydrogen fuel made today is called gray hydrogen. It's made by a process known as steam-methane reforming (SMR), powered by gas and coal, and therefore the source of CO2 emissions. Gray hydrogen is not a better solution on its own. However, its current accessibility is leading companies to build hydrogen infrastructure that will work with greener hydrogen fuel options.

Gray hydrogen is most helpful due to its wide availability. The infrastructure built to use it will transfer to greener hydrogen fuels seamlessly.

Blue hydrogen, which is made through SMR but includes emissions capture, may be part of the transition. The end goal is green hydrogen, produced through electrolysis powered by renewable energy. Its only byproduct is oxygen.

Heavy commercial vehicles are one of the leading use-cases for hydrogen fuel. Tractor-trailers and industrial equipment all need more power than electric vehicles can provide, but in order for hydrogen to be a viable solution, they also need a national refueling infrastructure.

A focus on commercial customers — and trucking routes — could be what hydrogen needs to thrive. Most truckers follow the same routes across the country, which would make it easy to strategically place hydrogen fueling stations.

Ballard Power Systems has bet big on commercial FCEVs, placing fuel cells in over 2,000 commercial trucks and starting collaboration on a high-power fuel cell that could work in ships. The company has the bona fides to back up its work: It's been working to revolutionize energy since 1979. And investors clearly believe the company has more to give. Its most recent funding round, a post-IPO round in early 2021, brought in $550M.

Hydrogen fuel cell airplanes, on the other hand, may not happen for years to come. Aerospace company ZeroAvia, founded in 2017, achieved an 8-minute hydrogen-powered flight in 2020. The plane may have been the largest ever to fly using hydrogen cells, but it was a five-seater propeller plane, and four of the seats had to be removed to make room for the hydrogen tanks. One of the next steps toward viability will be reducing the size and weight of hydrogen storage containers.

Additionally, fuel cells only provide enough power for smaller aircraft. McKinsey predicts hydrogen fuel may eventually be used for combustion in commercial airliners, but that day is far off.

Energy storage

Energy storage has become more important as the grid incorporates more renewables. Because peak renewable generation rarely lines up with peak demand, we miss out on these sources' true capacity. Innovations in battery development are pushing our energy storage capabilities further, and some of the newest technologies in the field are reimagining what a battery looks like.

The power grid of the future must be able to capture all the power generated and store it as potential energy. Potential energy can exist in many forms. A thermos of hot coffee, for instance, has potential heat energy that can be transferred — to the air, to your cold fingers, etc. — when opened. Long-duration energy storage (LDES) uses the same principle, with the goal of holding two weeks' worth of power for any given system. By contrast, batteries can only hold a few hours' worth of power before costs become prohibitive.

McKinsey expects the use of renewables and LDES could cut power sector emissions by up to 15% by 2040. Because many of these energy storage systems are cheap and readily accessible, they can also cut the cost of decarbonization. The simplicity of the following LDES systems may help them win over more costly and less scalable alternatives, including lithium-ion batteries and hydrogen storage.

Thermal

Sensible heat storage, the most common form of a thermal energy storage (TES) system, involves using excess energy to heat up material to extreme temperatures. When the grid needs to draw on energy stores, the heated material flows through some form of heat exchanger. Whether by boiling water to create steam or pressurizing a gas, the heat makes turbines spin, and the discharged (cooled) material is sent back to the start of the process.

Water, salts, sands, and rocks are the most common materials used to store heat. Once charged, materials sit in insulated silos until the grid needs more power. The raw materials are easy to come by, and silos are modular, cheap, and simple to construct.

The National Renewable Energy Lab's prototype ENDURING heats silica sand to 1,200°C (almost 2,200°F) and stores it in insulated concrete silos. Each apparatus stores up to 26,000 MWh of thermal energy.

Silica sand is abundant and cheap and comes with no major end-of-life ecological impacts. The NREL has suggested the ENDURING systems might use the infrastructure from old gas- and coal-fired power plants to further reduce costs.

Antora Energy recently announced a $50M Series A funding round to begin development on a TES system that charges blocks of solid carbon. Aimed at industry rather than utilities, Antora can provide the heat needed to make materials like steel or concrete. Because carbon doesn't liquefy until 3,600°C (over 6,500°F), it can easily hold enough heat for energy-intensive manufacturing. The company plans to have its first units ready by late 2023.

Pumped hydro storage

By moving water to the top of a system during times of high energy generation, pumped storage hydropower (PSH) primes traditional turbine systems to create energy during lulls. All that's needed are two connected reservoirs, one at a higher elevation than the other, and a system that transfers water between them. During times of excess power generation, a PSH system pumps water from the lower reservoir into the upper reservoir. Opening the channel between the two allows the water to flow back down, turning turbines and generating electricity for the grid.

PSH can be built in an open- or closed-loop system. Both systems involve two reservoirs. For open-loop PSH, the lower reservoir is created by damming an existing river. Constructing new dams impacts river ecosystems and earning approvals for these projects is difficult due to the environmental impacts. Closed-loop systems, on the other hand, call for the construction of two new reservoirs. Because the latter type of PSH is not connected to any natural water features, it is more environmentally friendly.

PSH isn't a new method; it's used for around 95% of all utility energy storage in the country. The system was incredibly popular between the 1960s and 1990s as nuclear energy expanded. With the current focus on renewables (and a potential nuclear renaissance), the US government is looking to PSH again. The Department of Energy has noted our national potential to double PSH capacity by adding new plants around the nation.

Rye Development is one of the companies leading the way with new projects. It recently received $150M to fund 22 hydroelectric and hydro storage projects across the US. Its first PSH initiative, the Swan Lake Energy Storage Project in Klamath County, Oregon, will save nearly 600,000 tons of CO_2 annually.

Gravity

Gravitational storage is built on the same principles as pumped hydro storage. This power storage method involves using a crane to heft heavy composite bricks when energy production exceeds use. Bricks are stacked on each other. To retrieve the power stored in them, one of the crane arms picks up a brick and lets gravity lower it down to the earth. The crane motor spins in reverse, creating power.

The bricks can be made out of anything: dirt excavated during construction, waste products like the coal ash that's left after combustion, or tailings from mining operations. Using locally available resources or waste products means a faster process and lower prices.

Energy Vault makes three types of gravity storage platforms, two of which rely on cranes. Its newer EVx model is a building with a trolley system and racks near the ceiling. The system trolleys bricks up to store power and lowers them down to retrieve it. Its biggest downside is the acreage required. Constructing these towers near solar or wind farms is the most feasible option. They're also a good fit for industry, like mines or large-scale manufacturing plants that have space to spare. Energy Vault's Series C funding totaled $100M, and the company went public after finalizing an SPAC merger in early 2022. But gravity storage doesn't always need a tower or high building to work. London-based Gravitricity has launched its systems in abandoned mine shafts, using winches and cables to raise and lower blocks as needed.