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Getting to 100% renewables requires cheap energy storage. But how cheap?

New research gives energy storage a cost target.

By **David Roberts** | **@drvox** | **david@vox.com** | Aug 9, 2019, 11:30am EDT

Some believe that carbon-free renewable energy sources can supply 100 percent of US energy. | Shutterstock

One of the most heated and interesting debates in the energy world today has to do with how far the US can get on carbon-free renewable energy alone.

One faction believes that renewables can supply 100 percent of US energy, with sufficient help from cheap energy storage and savvy management of demand.

Another faction believes that renewables will ultimately fall short and need assistance from nuclear power and natural gas or biomass with carbon capture and storage.

This war is largely being waged behind the scenes in competing academic papers, but it is highly relevant to current events as a whole host of states and cities are passing laws targeting "100 percent clean energy." Some, like Hawaii, specifically target 100 percent renewables. Some, like Washington state, target 100 percent "clean," allowing room for non-renewable sources.

Which target is more realistic and prudent? Just how far can renewables get?

At the heart of the debate is the simple fact that the two biggest sources of renewable energy — wind and solar power — are "variable." They come and go with the weather and time of day. They are not "dispatchable," which means they cannot be turned on and off, or up and down, according to the grid's needs. They don't adjust to the grid; the grid adjusts to them.

That means a grid with lots of renewables needs lots of flexibility, lots of different ways of smoothing and balancing out the fluctuations in wind and solar. When people predict that renewables will fall short of 100 percent, what they are predicting is that we won't be able to find enough flexibility to accommodate them (at least not fast enough). They will require "firming" by dispatchable, nonrenewable sources.

There are many sources of grid flexibility, but the one that seems to have the most potential and is laden with the highest hopes is energy storage. To a first approximation, the question of whether renewables will be able to get to 100 percent reduces to the question of whether storage will get cheap enough. With cheap-enough storage, we can add a ton of it to the grid and absorb just about any fluctuations.

But how cheap is cheap enough?

That question is the subject of a fascinating new bit of research out of an MIT lab run by researcher Jessika Trancik (I've written about Trancik's work before), just released in the journal *Joule.*

To spoil the ending: The answer is $20 per kilowatt hour in energy capacity costs. That's how cheap storage would have to get for renewables to get to 100 percent. That's around a 90 percent drop from today's costs. While that is entirely within the realm of the possible, there is wide disagreement over when it might happen; few expect it by 2030.

However, there are twists and turns to this tale, and a happier ending than that summary might indicate. Let's take a closer look.

Residential batteries. | Shutterstock

Putting energy storage to the ultimate test

In a clever twist on the traditional modeling approach — which seeks the cost-optimal path to decarbonization, given a particular set of demand and technology-cost assumptions — Trancik's team starts by constructing a scenario in which renewable energy and storage provide 100 percent of US energy and then asks: How cheap would storage have to get for this to be the cheapest option?

They didn't set an easy target. Most renewable energy modeling matches the performance of a resource mix against a year or two of weather data on solar and wind availability in particular locations. Trancik's team chose four locations (Arizona, Iowa, Massachusetts, and Texas) and gathered *20 years* of data on them.

It's important to test renewable energy over longer time spans. In addition to daily and weekly fluctuations in solar and wind, there can be yearly or even multi-year fluctuations. And indeed, by looking back over 20 years, the team found several rare events in which wind and solar were both unusually low for an unusually long time. These rare events represent a spike in the amount of storage needed. Planning for them substantially increases the cost of a pure-renewables system.

For each of the four states, Trancik's team modeled a renewables+storage system that has an "equivalent availability factor" (EAF) of 100 percent. That means the system would precisely match supply to demand, providing baseload, intermediate, and peaking power, given real-world resource-availability conditions, in every hour of every day, over 20 years.

(Actually, they did multiple scenarios per state: solar-only, wind-only, an optimized solar-wind mix, and all of those with two different tiers of storage technologies. I'm trying to keep it simple.)

That is a high bar: enough storage to accommodate any possible fluctuation of wind and solar over two decades.

The basic result is that storage energy-capacity costs have to fall to about $20 per kilowatt hour for a renewables+storage system to be cost competitive at the task of providing 100 percent of US energy.

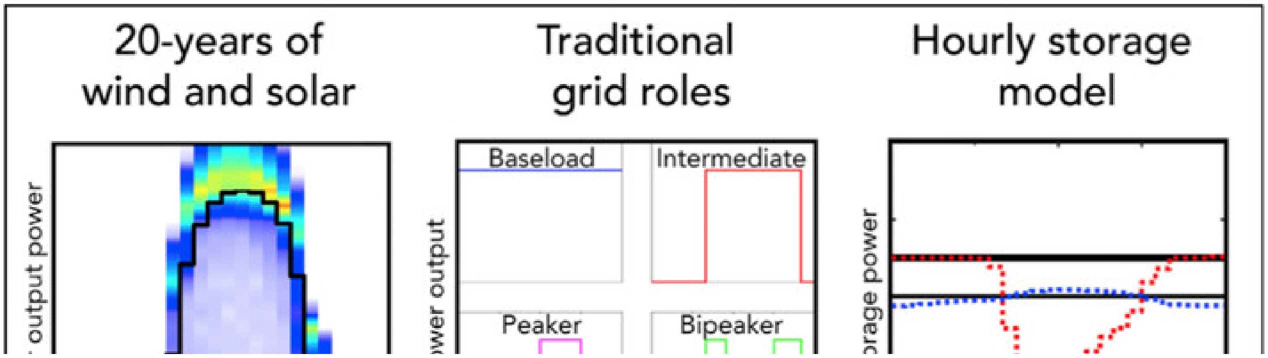
That's an average. Here are the gory details:

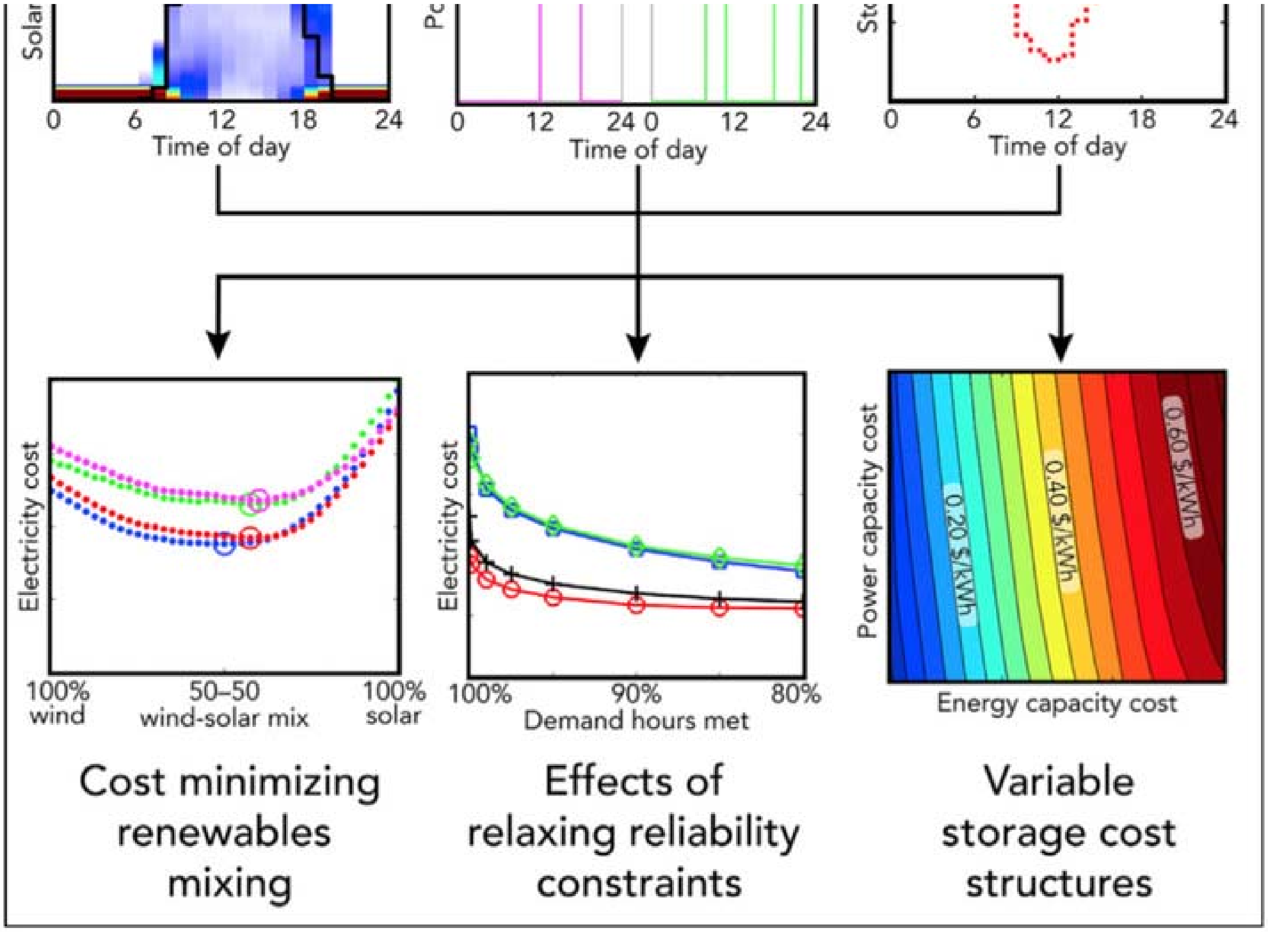
> **A cost-optimal wind-solar mix with storage reaches cost-competitiveness with a nuclear fission plant providing baseload electricity at a cost of $0.075/kWh at an energy storage capacity cost of $10-20/kWh. To reach cost-competitiveness with a peaker natural gas plant at $0.077/kWh, energy storage capacity costs must instead fall below $5/kWh (at a storage power capacity cost of $1,000/kW). To provide baseload, intermediate, bipeaker, and peaker electricity at $0.10/kWh with an optimal wind-solar mix, energy storage capacity costs must reach approximately $30–70/kWh, $30v90/kWh, $10–30/kWh, and $10–30/kWh respectively.**

These are extremely daunting cost targets — not outside the realm of possibility, but well beyond the edge of most mainstream projections. (We'll discuss what kind of storage technologies might meet that target in a moment.)

On the surface, this might look like confirmation that an all-renewables+storage system is unrealistic, that it relies on fantastical drops in technology costs.

But scratch a little deeper and the news for all-renewables fans looks much better.





A sampling of graphics from the paper (and sufficient explanation, I trust, for why I didn't use more). | Joule

Storage can probably win well before it hits the $20/kWh target

As I said, these researchers set an extremely high bar: a system with all-renewable energy, with flexibility handled entirely by storage, adequate to meet demand at every hour of every day for 20 years.

Soften any of these restraints even a little and the cost target that storage must meet rises to something far more tractable.

First and most notably, loosen the amount of time that the system must meet demand and things get *much* **easier for storage. And a 100 percent EAF is a little crazy anyway; the existing power system is not up and available 100 percent of the time. There are brownouts and blackouts, after all.** *No* **power system is 100 percent reliable.**

Trancik's team found that if the EAF target is lowered from 100 to 95 percent, the cost target that storage must hit rises to $150/kWh. (More specifically, lowering the EAF reduced the total cost of energy storage by 25 percent for the first tier of storage technologies and 48 percent for the second tier.) That's a much more tractable number, within reach of existing technologies.

Why does lowering the EAF so little ease the pressure on storage so much? The explanation is in those rare meteorological events of extended low wind and sun. They don't happen often over a 20-year span, but building enough storage to deal with them when they do happen makes the last few percent of EAF exponentially more expensive. To lower the EAF to 95 percent is to say, "something else can handle those rare events." (As to what that something might be, we'll discuss that later.)

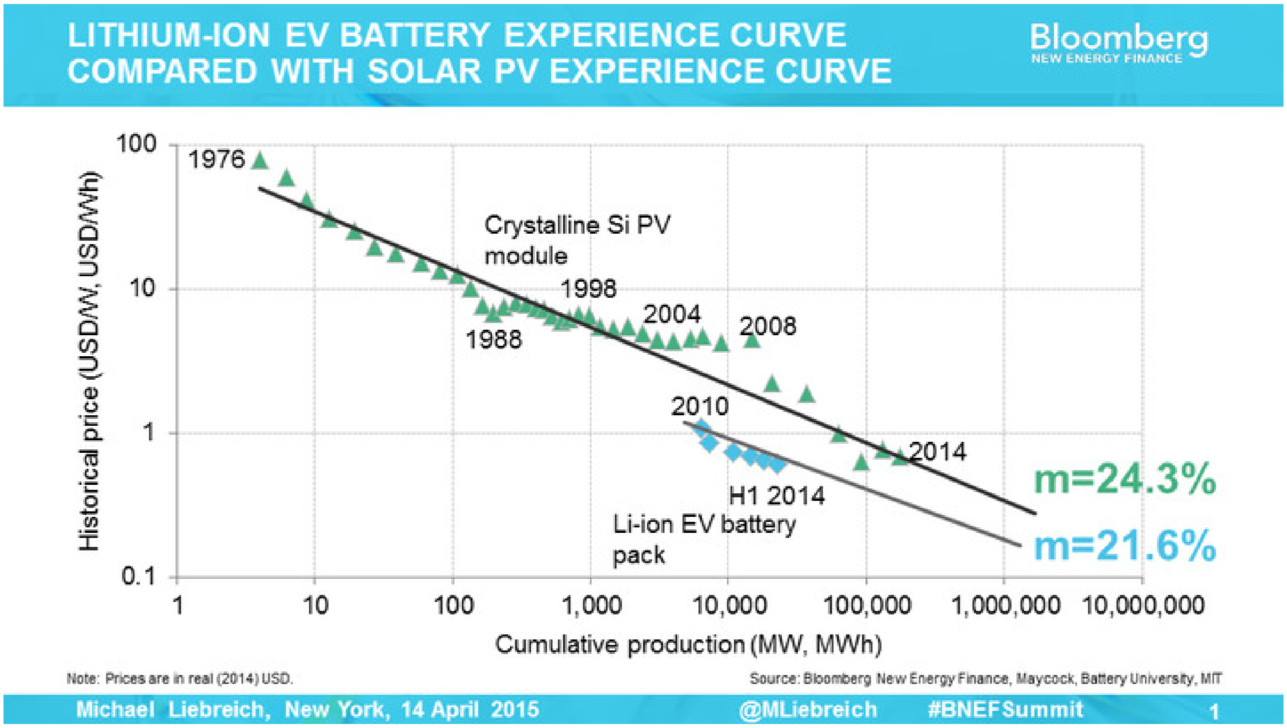
Second, remember, the team is modeling a system in which storage is doing almost all the flexibility work. In fact, there are other sources of grid flexibility. My favorite candidate for flexibility dark horse is "load flexibility," demand-side programs that can shift energy consumption around in time. Another source of flexibility is enhanced long-distance transmission, to carry renewable energy from regions that produce it to regions that need it. Another is dispatchable renewables like run-of-the-river hydro and advanced geothermal.

All of those sources of flexibility will grow and help to smooth out renewables. Storage won't have to do all the work on its own. That, too, should ease the price pressure.

Third, a renewables+storage system also gets easier if *renewables* get cheaper. The numbers that Trancik's team use for renewables are quite conservative. (For instance, $1/Watt solar costs are already being beat routinely in the US.) If renewable energy continues to defy expectations and plunge in cost, it would become cheaper and easier to oversize renewables and curtail the excess energy. That in turn would ease pressure on storage.

In short, the headline $20/kWh cost target for energy storage is almost certainly more stringent than what will be required in the real world. Even the $150/kWh target required for an EAF of 95 percent is likely too stringent. In the real world, storage will be assisted by other forms of grid flexibility like long-distance transmission, load flexibility, and microgrids, along with regulatory and legislative reforms. And renewables will probably continue to get cheaper faster than anyone predicts.

So let’s call the target $150-$200, or thereabouts. Can storage hit that?



BNEF says li-ion batteries are on the same trajectory as solar PV. | (BNEF)

Energy storage is developing rapidly and within striking distance of transformative costs

There are two key characteristics of a storage technology: power capacity and energy capacity. Roughly speaking, power capacity refers to how fast you can get energy out of it, measured in kW; energy capacity refers to how much energy you can store in it, measured in kWh. Each is priced separately,

power capacity costs and energy capacity costs. The latter is the number we've been using for targets (I'll explain why in a sec).

Remember how the study divides storage technologies into two tiers? Tier one technologies were modeled with high power capacity costs ($1,000/kW) and low energy capacity costs ($20/kWh). They include things like pumped hydro, compressed-air storage (CAES), and some proposed flow batteries, which use cheap and abundant elements dissolved in large volumes of water to store energy. They tend to have lower energy density than tier two technologies, but because of their low energy capacity costs, they are good for long-term grid storage.

Tier two technologies were modeled with relatively lower power capacity costs ($700/kW) and higher energy capacity costs ($150/kWh). They include things like further advanced lithium-ion batteries, other battery chemistries, flywheels, and supercapacitors that are more suited to short-duration, high-power applications like, say, vehicles or appliances.

The overall levelized cost of energy storage (LCOSE) in the system "shows a higher sensitivity to storage energy capacity costs than to storage power capacity costs," mainly because optimally sized systems need a *lot* **of storage, enough to run between 6 and 180 hours at a time, depending on the system and location. That means the low energy capacity costs of long-term storage are prized; that's why they are used in the study as targets.**

So, with this information in our back pocket, let's look at how storage technologies are coming along (this is worth a much longer post, but consider this a snapshot). Remember, in the real world, storage is going to be competing against other sources of grid flexibility, including nonrenewable sources like nuclear and natural gas with CCS.

Can storage out-compete them?

A 2017 report from the International Renewable Energy Agency (IRENA) contains some intriguing projections.

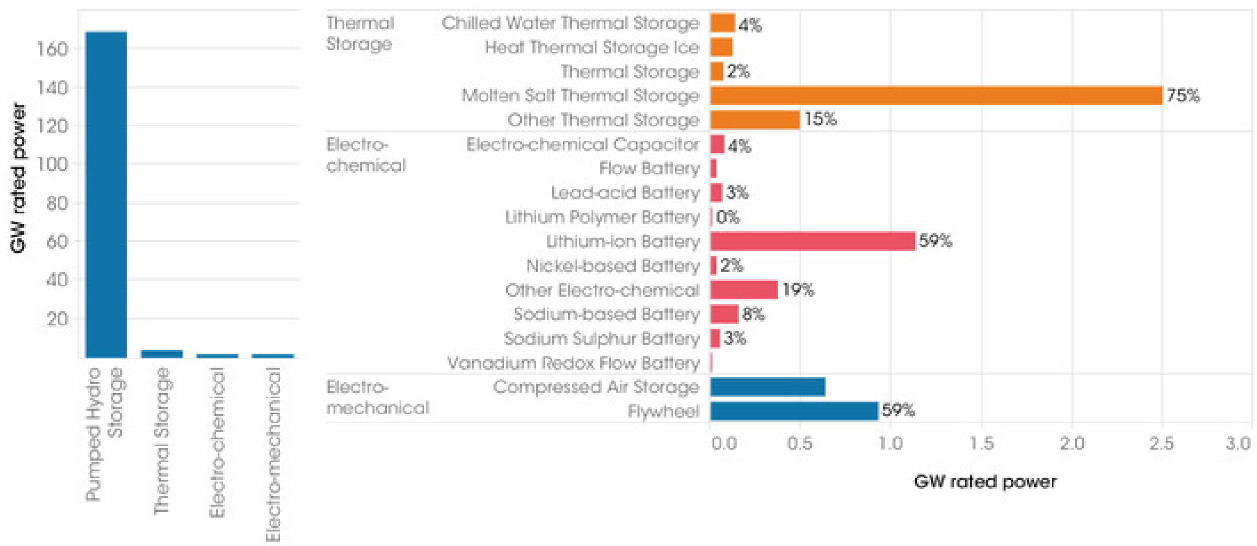


Figure ES8: Global operational electricity storage power capacity by technology, mid-2017

The energy storage currently installed … is mostly pumped hydro. | **IRENA**

It expects, by 2030, "a drop in the total installed cost for Li-ion batteries for stationary applications to between USD 145 per kilowatt-hour (kWh) and USD 480/kWh, depending on battery chemistry." Hey, $145 is well within our target range!

Nonetheless, lithium-ion batteries are limited. Researchers generally treat the raw materials costs of a storage technology as the lower possible bound of its total costs. Manufacturing and transportation costs can be lowered with scale, but materials costs are stubborn, and the materials involved in Li-ion batteries alone are costly enough that they will likely never hit $20/kWh. In the $150 range, though — that's doable.

(One interesting possibility: there are going to be gigawatts worth of discarded electric-vehicle batteries soon, each with energy capacity remaining. There are efforts afoot to bundle them together as grid storage, with potentially extremely low LCOSE. An area to watch.)

How about flow batteries? "The two main flow battery technologies — vanadium redox flow and zinc bromine flow — had total installation costs in 2016 of between USD 315 and USD 1,680/kWh," IRENA reports. "By 2030,

the cost is expected to come down to between USD 108 and USD 576/kWh." Yes, $108 is well within our target range. (Note that there are flow battery companies already claiming to beat that.)

High-temperature sodium sulphur (NaS) and sodium nickel chloride batteries have been around for a while, but they are also expected to get much cheaper. "Cost reductions of up to 75% could be achieved by 2030, with NaS battery installation cost decreasing to between USD 120 and USD 330/kWh," says IRENA. "In parallel, the energy installation cost of the sodium nickel chloride high-temperature battery could fall from the current USD 315 to USD 490/kWh to between USD 130 and USD 200/kWh by 2030." Again, at the lower end, well within our target range.

CAES costs are extremely site-specific, as they depend on a reservoir in which to pump the air. "The typical installation cost is estimated to be approximately USD 50/kWh," says IRENA, "possibly dropping to USD 40/kWh if an existing reservoir is available."

Then there are thermal-storage options, like the increasingly popular option of storing electricity as heat in molten salt, with claims of energy capacity costs as low as $50/kWh.

Wind and grid batteries in Australia. | Tesla

And there is furious work going on around a number of promising new technologies.

There is a lot of interest around flow batteries using sulfur, mainly because the materials costs are insanely low — this paper puts them at $1/kWh — which opens the possibility of high-volume storage, even though the energy density may be low and the power itself expensive. One of the authors of that paper, MIT professor Yet-Ming Chiang, co-founded a hot new startup called Form Energy that is explicitly going after long-duration storage.

Another startup, Antora, has developed an extremely cheap thermal storage system — it stores energy as heat in inexpensive raw materials and converts it back to electricity with a thermophotovoltaic heat engine — that it claims will come in at under $10/kWh.

Another startup, e-Zn, has an electrochemical cell, like a battery, but with a twist. Energy is stored as zinc metal in a chamber between the charging and discharging sections; it is stable and can be stored for long periods of time. Its simple mechanical operation and cheap materials make it a contender for long-term storage.

I could go on forever — I'm sure to get dozens of emails from companies I left out — but the point is that a whole portfolio of storage options is available, with lots more options in development, many of which can reasonably be expected to get within the cost range that Trancik's team says can enable renewables to reach a 95 percent EAF.

Storage is rapidly evolving, diversifying, and falling in cost, to the point that wind and solar power plants coupled with storage are beginning to compete directly with fossil fuel power plants on cost. That's only going to accelerate as both renewables and storage get cheaper. Providing *all* of US power, all

day every day, will require oversizing renewables and installing an enormous amount of storage, but if they get cheap enough, that's what we'll do.

To put that more plainly: A US energy grid run entirely on renewable energy (at least 95 percent of the time), leaning primarily on energy storage to provide grid flexibility, may be more realistic, and closer to hand, than conventional wisdom has it.