INSTITUTE FOR PROGRESS

February 2024

HOW TO SAVE AMERICA'S TRANSMISSION SYSTEM

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Contents

The American power grid is sometimes called “the world’s largest machine,” with its more than 500,000 miles of high-voltage transmission lines, 5 million miles of distribution lines, and thousands of power plants.[1] Decarbonization will make it even larger. If we aim to transform the power grid to renewables, the resulting infrastructure project will be as big as anything America has ever built. For scale, in 2023 dollars, the Interstate Highway system cost roughly $250 billion,[2] and the Apollo Program cost approximately $300 billion.[3] According to the NREL, decarbonizing the US electrical grid will cost between $330 and $740 billion.[4]

The reason it costs this much is that, of the 73.5 quadrillion BTUs of energy consumed by Americans in 2021, less than 20% was provided via electric power.[5] By one estimate, decarbonization will require quadrupling electricity generation.[6] An NREL model[7] similarly estimates that reducing emissions by 80% from 2005 levels will require nearly tripling electricity generation by 2050. But though the destination is clear — producing energy without climate-altering carbon dioxide — the path that will take us there is uncertain.

Past observers of America’s energy policy believed we had to choose between the “hard path” of large-scale industrial buildout, and the “soft path” of localist, small-scale energy. Today, we may be able to chart a third course that takes elements from both. Regardless of the path, one thing is clear: the government must commit to building new grid infrastructure on a remarkable scale.

The modern electrical grid is an ungainly beast, and adapting it to the modern age will require grappling with the particular way it developed. Historically, the American electricity industry grew by increasing the scale of power plants and networks, which made electricity cheaper until the 1970s. But today’s technologies, like solar and wind, don’t benefit from massive scaling. Instead they introduce new challenges that make it much harder to balance electricity production and consumption. Furthermore, the US faces significant barriers to building new electrical infrastructure, with prohibitive costs and time-consuming permitting processes. The priority of policy makers must be to make it as easy as possible for developers to build the necessary transmission to decarbonize.

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1 Independent Electricity System Operator, “The World’s Largest Machine: The North American Power Grid,” Independent Electricity System Operator, last modified 2020.

2 TRIP, “Restoring the Interstate: Strategies to Rebuild America’s Economy,” TRIP Report, July 2020.

3 “Cost of Apollo,” Planetary Society, accessed January 23, 2024.

4 U.S. Department of Energy, “NREL Study Identifies Opportunities and Challenges in Achieving U.S. Transformational Goal,” U.S. Department of Energy, accessed January 23, 2024.

5 U.S. Energy Information Administration, “U.S. Energy Facts Explained,” U.S. Energy Information Administration, accessed January 23, 2024.

6 Saul Griffith, “Electrify: An Optimist’s Playbook for Our Clean Energy Future,” MIT Press, 2021.

7 Brinkman, Gregory, Dominique Bain, Grant Buster, Caroline Draxl, Paritosh Das, Jonathan Ho, Eduardo Ibanez, et al. 2021. The North American Renewable Integration Study: A U.S. Perspective. Golden, CO: National Renewable Energy Laboratory. NREL/TP-6A20-79224.

US electric power consumption by use 1887-1921, in kilowatt-hours

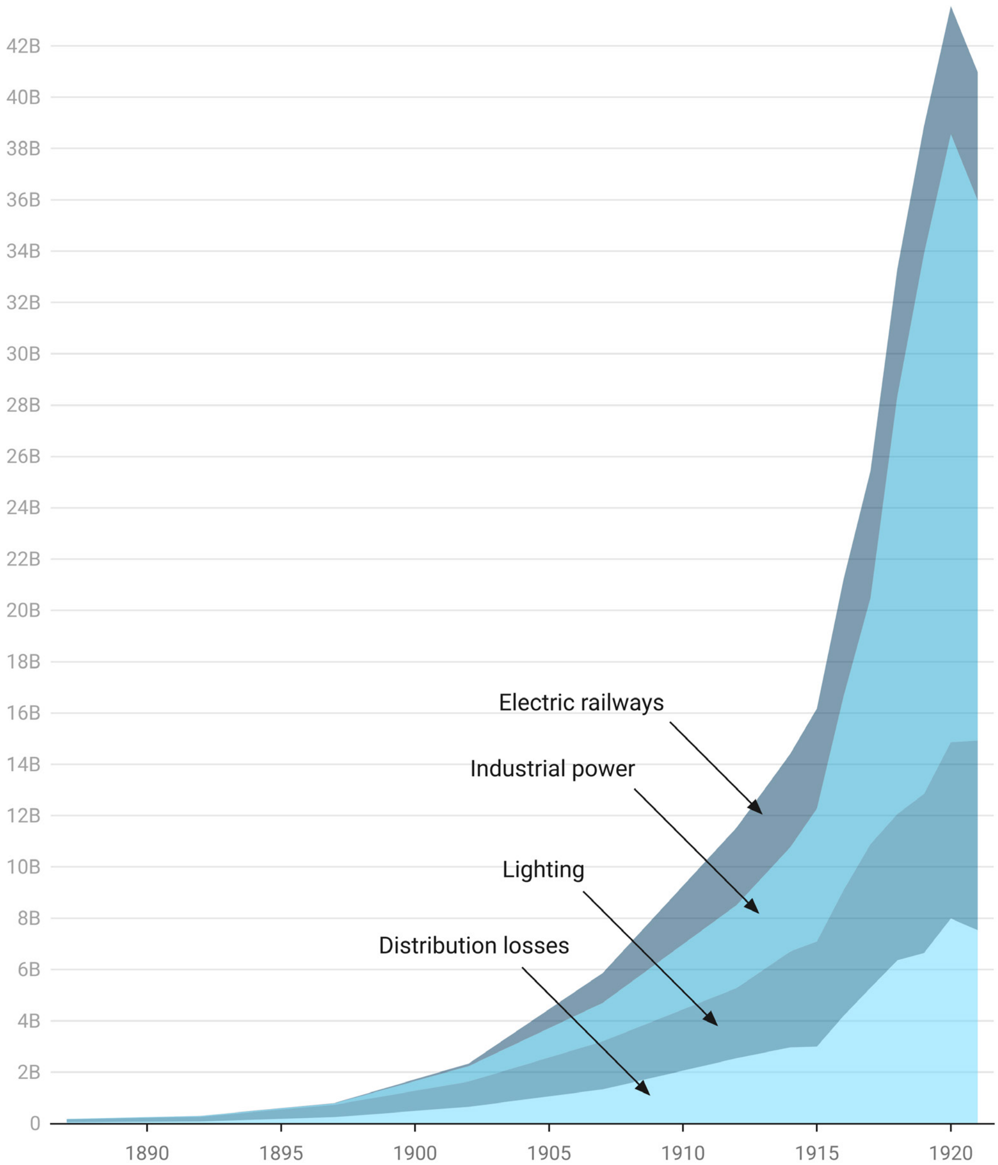


Chart: Brian Potter. Source: Electrical World, 1922. Created with Datawrapper.

The Limits of Scale

For most of US history, electricity became abundant by scale[8] — making power plants larger, tying them together in larger grids, and supplying larger numbers of customers at a cheaper price. Today, we're faced with rebuilding the system to use lower-carbon sources of electricity generation, while expanding it to meet increasing demand. But whereas historically power production grew most with massive, centralized stations that provided steady, directly controllable power, today's economics of production growth are more complicated.

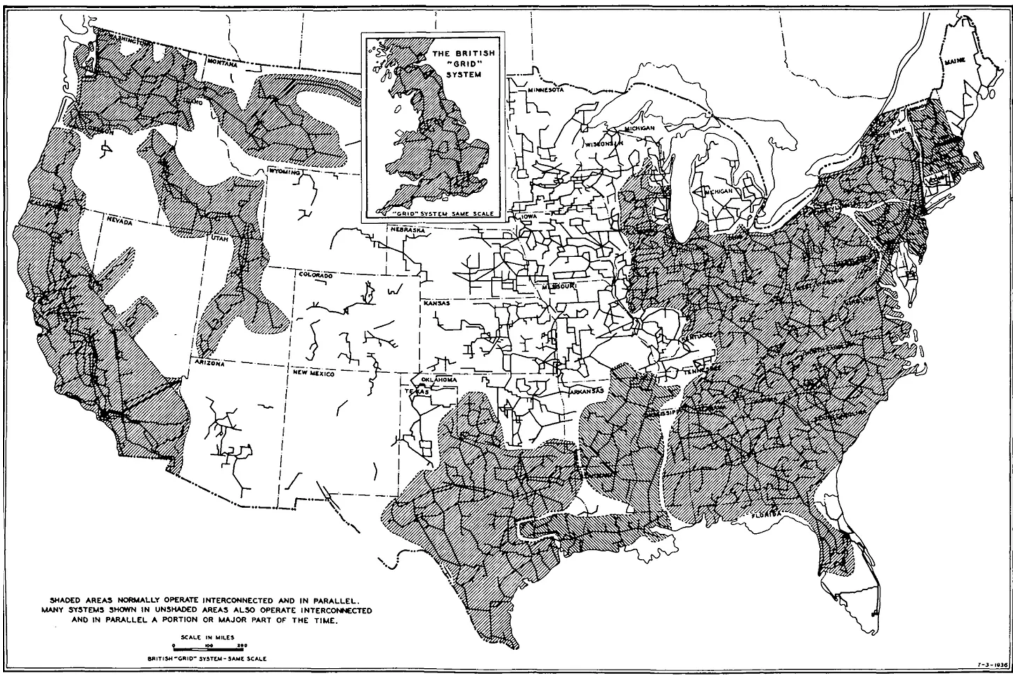
The two most common early modes of power production, steam turbines and hydroelectricity, became more efficient as they got larger. The benefits of scale pushed the electric power industry to adopt a "grow and build" strategy: building larger, more efficient stations and

8 Construction Physics, "The Grid Part II: The Golden Age of Electrical Engineering," Construction Physics, accessed January 23, 2024.

connecting them to as many customers as possible. By the 1920s, grow and build "appeared to be the only possible and logical approach for running a utility company" (Hirsch).

Increasing scale was achieved both by vertical consolidation and horizontal cooperation. Power companies pooled their resources, building large power stations which were more efficient than multiple smaller stations. Even companies that didn't invest in shared generating plants began to interconnect their systems by constructing thousands of miles of high-voltage transmission lines. By 1934, these huge interconnected systems spanned thousands of miles and connected millions of customers. By the 1960s, most electric power providers had tied themselves into a small number of interconnected systems.

Interconnected power systems in the US in 1936[9]



As power plants continued to grow more efficient, economies in production meant the price of electricity declined nearly 60% in real terms between 1945 and 1965. But in the 1960s and 1970s, the grow and build strategy stopped working. Power plant efficiencies peaked. The efficiencies of larger power units began to be offset by their increasing complexity — larger units had more components, which required more maintenance and increased the likelihood of failure. From 1950 to 1970, the size of the largest steam turbine rose by a factor of 6, but since then, maximum turbine sizes have increased just 30%.The transmission system faced similar difficulties. Attempts to tie the US grid into a single continent-wide grid in 1967 failed: the small number of connections lacked the capacity to keep Eastern and Western grids in sync, and after eight years of operation they were removed. Today, the US electrical grid consists of three separate synchronous grids — the Eastern Interconnection, the Western Interconnection, and the Texas Interconnection — which can share power over a small number of high voltage DC transmission lines that don't require the grids to be in sync.

When scale stopped working, electricity stopped getting cheaper. Whereas prior to 1970 the price of electricity had continuously fallen, from 1973 to 1983 the price of electricity increased nearly 30% in real terms (of course, the global energy crisis played a role).

9 Sporn, Philip, "Interconnected Electric Power Systems," Electrical Engineering Vol 57, Issue 1, pp16-25, 1938

Today's power-generating technologies largely don't benefit from being built as large as possible. For instance, solar power has a much smaller "minimum efficient scale." Unlike other sources of electricity, which get cheaper as plants get larger (up to several hundred megawatts), solar PV starts to see diminishing returns in plant size around 20MW.[10] Solar producers are thus less incentivized to build large centralized power stations.

Although most wind and solar[11] power is generated at large, utility-scale "farms," solar power is increasingly generated via rooftop panels mounted to individual buildings, which generate power in the kilowatt range. These "distributed energy resources" (DERs) are typically controlled by the individual home or business owner, not the utility company.

Besides being another variable source of generation, DERs can put stress on the grid. Most distribution systems were designed for one-way flow from central power stations to consumers, but high-enough DER penetration can cause power to flow from customers back through substations to transmission lines, a reverse flow the system wasn't designed for.

Increased Variability

Another challenge is that the grid increasingly incorporates new, small, highly variable sources of power. In our current grid system, electricity generation and consumption must balance day by day and minute by minute. When electrical generation is on-demand and provides a steady, predictable amount of power, this is comparatively straightforward. Errors in load forecasting are typically on the order of 1%.

Historically, electricity couldn't be cheaply stored, so it needed to be produced at the moment of consumption. The required generating capacity for a power company was thus driven by peak demand. Power plants had a well-defined amount of generation capacity, making it relatively straightforward to meet demand for electricity. Even variable sources of electricity, like hydroelectric dams, were predictable in the short term. Large networks of transmission lines tied together service areas, smoothing out peaks of demand and allowing power to be shared during emergencies[12].

But predictable sources of electricity (such as coal plants) are being removed from the grid. They're being replaced by sources like wind and solar, which fluctuate in their output based on whether the wind is blowing or the sun is shining. Between 2011 and 2020, roughly one third of US coal plants were shut down.[13] By 2030, another quarter are expected to be shuttered.[14] By contrast, two thirds of the 150 gigawatts of new electrical generation projects being tracked by the EIA are wind or solar.

10 Joachim Seel et al., "Utility-Scale Solar 2023 Edition," Lawrence Berkeley National Laboratory, 2023.

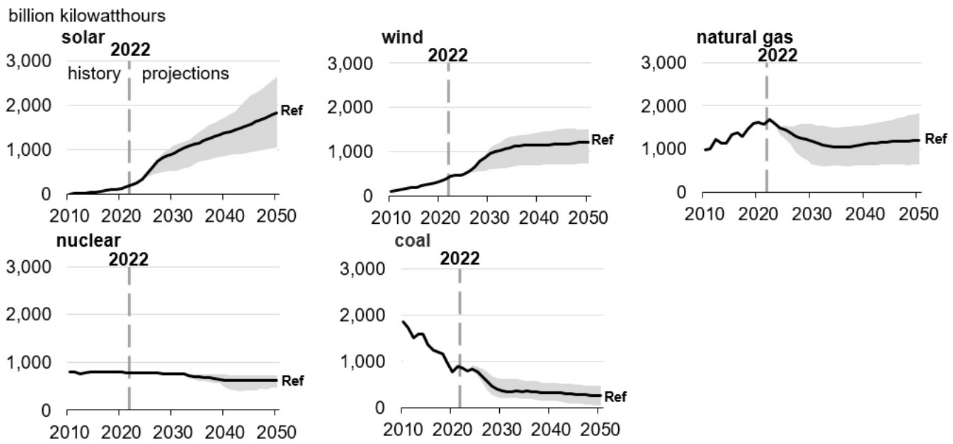
11 U.S. Energy Information Administration, "EIA Projects 38% of Electricity Generation Will Come from Renewables in 2050," U.S. Energy Information Administration, February 2023.

12 Lyman and North, 1938.

13 U.S. Energy Information Administration, "Natural Gas Prices Affect Electricity Rates in New England," U.S. Energy Information Administration, May 2023.

14 U.S. Energy Information Administration, "U.S. Electricity Generation from Renewables Expected to Grow 6% in 2022," U.S. Energy Information Administration, February 2023.

U.S. electricity generation by select technologies for all cases



Note: Shaded regions represent maximum and minimum values for each projection year across the AEO2023 Reference case and side cases

Ref=Reference case

Source: Annual Energy Outlook 2023 (AEO2023).

Via EIA.

With variable sources of generation, which might vary 15 to 30% from their projected next-day output (MIT 2011), greater reserve margins are needed to ensure demand can be met if variable generation is less than predicted.

What's more, distribution systems were historically designed with a "fit and forget" approach.[15] They were sized to accommodate peak load, but weren't built with monitoring or control systems that would allow the flexible management that variable sources of electricity require. Variable sources of electricity, like solar and wind (to a degree), also lack much of the grid-steadying effect provided by conventional generators (MIT 2011). Variable sources of electric power upend the logic on which the power grid was built. As Gretchen Bakke notes,[16] the grid "isn't made for modern power."

Similarly, utilities were historically incentivized to aggregate as many customers as possible onto a single grid because there was no way to store electricity cheaply, which meant the best way to reduce peak demand was by averaging the demand of many different customers. Even today, large-scale electricity storage is essentially non-existent.[17]

But this too is changing. There are currently over 500 gigawatts of planned energy storage capacity in the interconnection queue, nearly half the capacity of all existing US power plants.[18] Battery technologies more suitable for long-duration storage, such as iron-air batteries,[19] are being developed. And if the costs of solar power falls low enough, other low-carbon energy storage methods, such as hydrogen or methane synthesis, may become economical.

15 International Energy Agency, "Unlocking the Potential of Distributed Energy Resources," International Energy Agency, 2022.

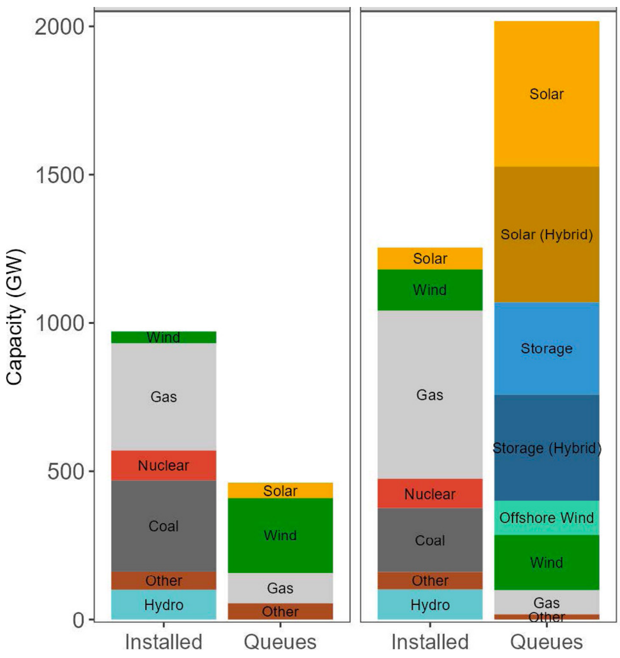
16 Gretchen Bakke, "The Grid: Fraying Between Americans and Our Energy Future," Amazon, accessed January 23, 2024.

17 U.S. Energy Information Administration, "Natural Gas Prices Affected Power Generation Fuel Mix in 2022," U.S. Energy Information Administration, January 2024.

18 Though only a small fraction of these storage projects will ultimately be built.

19 Form Energy, "Form Energy: A New Class of Cost-Effective, Multi-Day Energy Storage Systems," accessed January 23, 2024.

Entire U.S. Installed Capacity vs. Active Queues



Via LBL.

Some low-carbon sources of electricity don't have a variability issue, and can produce "firm" power. Nuclear power, which still provides nearly 20% of the US's electricity,[20] is one such technology. Another is geothermal. While traditional geothermal is limited to specific geological locations, enhanced geothermal systems (EGS)[21] could potentially[22] tap into heat energy[23] stored in the earth's crust at any location. But these technologies have their own challenges.[24] Enhanced geothermal is still in the early phases of development, and the US has a poor track record of building nuclear plants, rife with massive cost overruns[25] and wasted money when plants get canceled.[26] Prior to Vogtle Units 3 and 4, no civilian nuclear plant had been built in 30 years.

Decreasing Reliability

Even if these technologies are widely deployed, they will plug into an increasingly unreliable grid. Between the early 1990s and the early 2000s, the number of outages affecting more than 50,000 customers more than tripled. In 2009, a report from the DOE's Electricity Advisory Committee warned that the current electrical infrastructure "will be unable to ensure a reliable, cost-effective, secure, and environmentally sustainable supply of electricity for the next two decades."[27] Major disturbances to the electrical system are now at a 20-year high, the frequency of power outages has increased, and the average yearly total outage duration has more than doubled. In 2006, the average yearly duration of power outages in the US was seven times that

20 U.S. Energy Information Administration, "Frequently Asked Questions: How Much of U.S. Carbon Dioxide Emissions Are Associated with Electricity Generation?," U.S. Energy Information Administration, accessed January 23, 2024.

21 U.S. Department of Energy, "Enhanced Geothermal Systems Basics," U.S. Department of Energy.

22 Institute for Progress, "The Policy Interventions That Could Boost Geothermal," accessed January 23, 2024.

23 Eli Dourado, "Geothermal," accessed January 23, 2024.

24 Institute for Progress, "Hot Rocks Part Three: Barriers to Next-Gen Geothermal," accessed January 23, 2024.

25 Institute for Progress, "Nuclear Power Plant Construction Costs," accessed January 23, 2024.

26 HistoryLink, "Washington Public Power Supply System (WPPSS)," accessed January 23, 2024.

27 U.S. Department of Energy, "Electricity Advisory Committee (EAC) 2009: Keeping the Lights in a New World," accessed January 23, 2024.

of Germany. Since then, US grid outages have increased to 475 minutes on average per year, whereas in Germany they are just over 12 minutes a year. As the fraction of power provided by variable sources of electricity continues to increase, and as we see more extreme weather events, maintaining the reliability of the power grid will only get more difficult.

Major electrical disturbances per year

Via DOE OE-417 reports

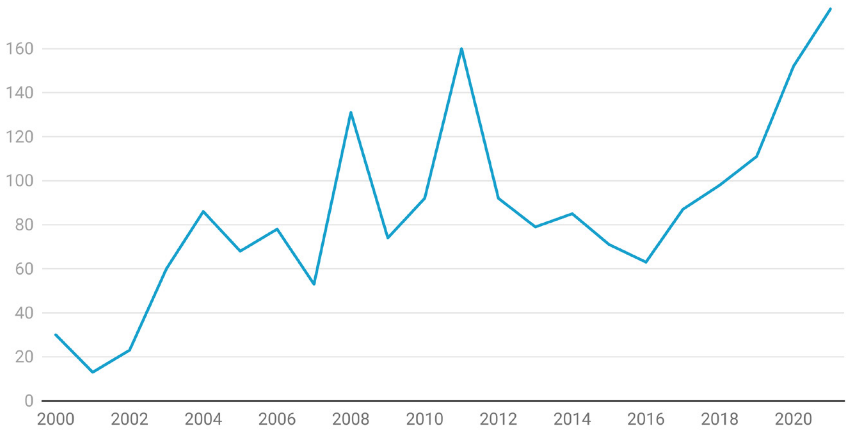
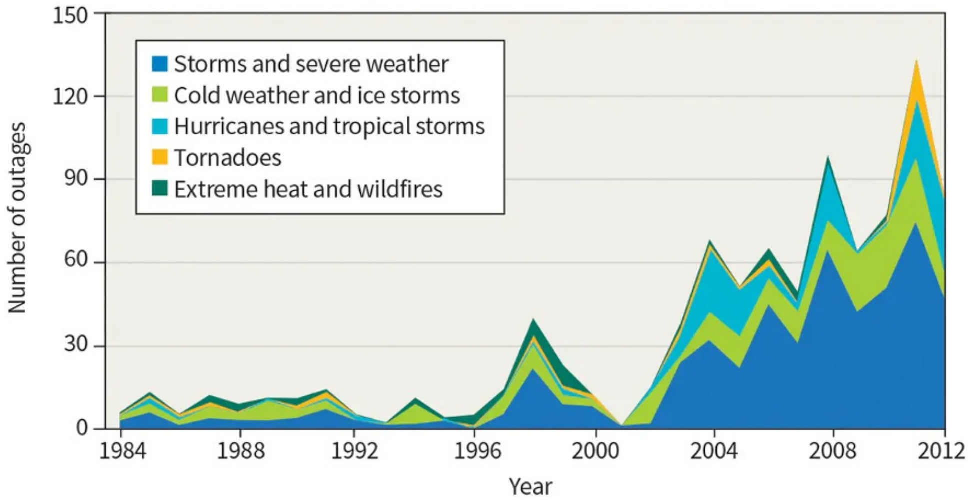


Chart: Brian Potter. Source: Climate Central. Created with Datawrapper.

Extreme Weather is Causing More Major Power Outages

(major = at least 50,000 customers affected)



Source: Climate Central.

Barriers to Building Infrastructure

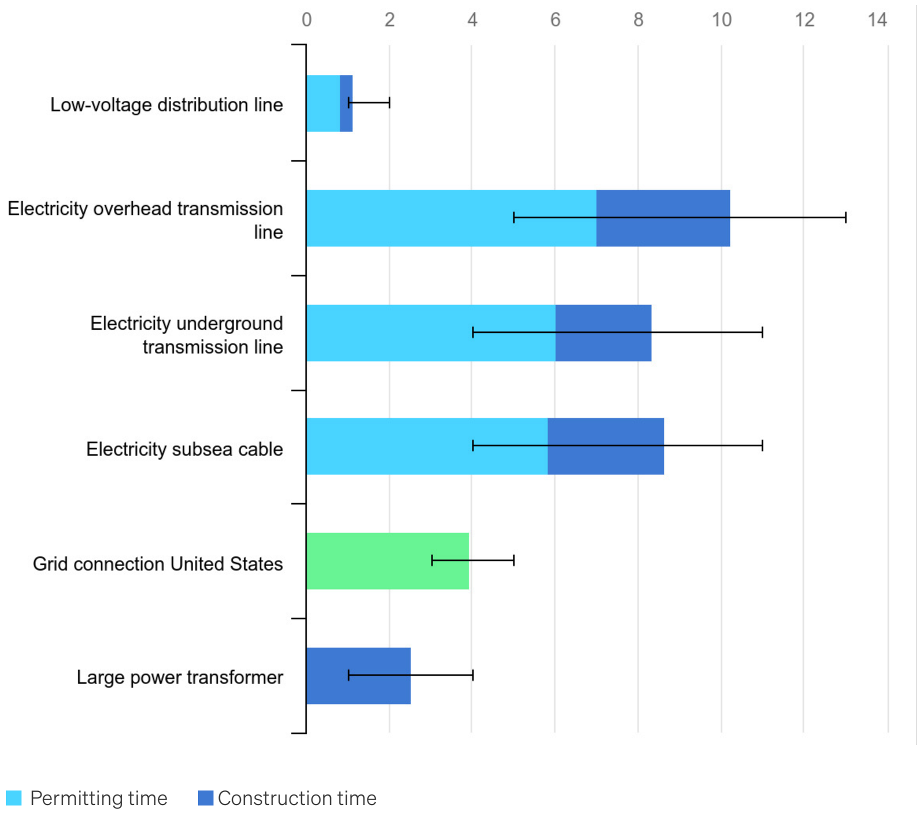
Despite the pressing need, we are unfortunately poorly-positioned to achieve the electrification necessary to decarbonize. Since the 1970s, it has become increasingly difficult to build electrical infrastructure in the US.

Some types of infrastructure have become exceedingly difficult to build. Nuclear power plants, for instance, have become almost impossible to build profitably in the US. Of the two attempts in the last 20 years, one was canceled after spending billions of dollars,[28] and the other is seven years late and $17 billion dollars over budget.[29] There are no new large nuclear plants in EIA's list of planned power plants.

Large hydroelectric power plants have similarly become near-impossible to build. Construction largely stopped in the 1970s due to environmental concerns, and US hydroelectric power production peaked in the mid-1990s, despite the fact that the US has only tapped roughly 16% of its potential hydropower resources.[30] While there are 80 planned hydroelectric projects currently being tracked by the EIA, they're all very small facilities.

In other cases, electrical infrastructure is incredibly time-consuming to build. Transmission lines, for instance, take on average 10 years to build in the US, and in some cases can take up to 20 years.

Average time to build electrical infrastructure in the US. Light blue is permitting time, dark blue is construction time.



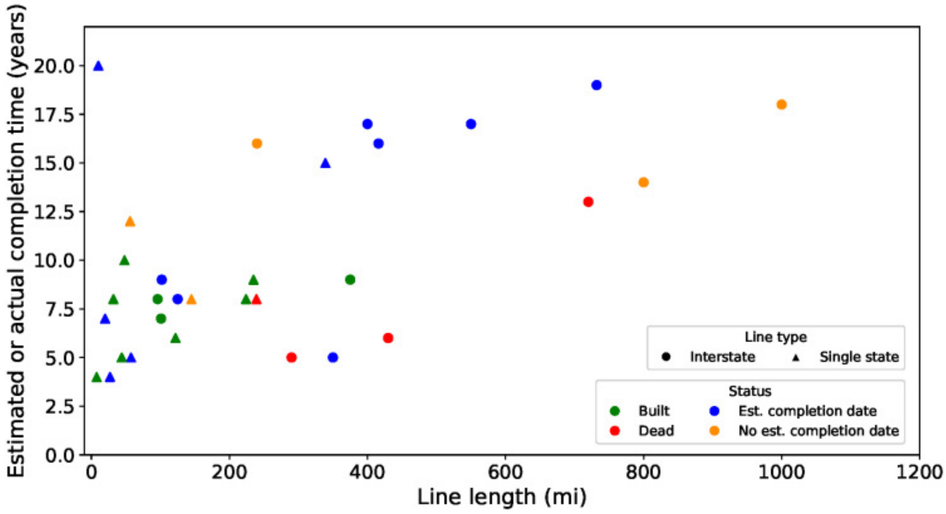
Via IEA.

28 The Intercept, "South Carolina's Green New Deal: How a State that Was Once the Epicenter of the Confederacy Became a Leader in Renewable Energy," The Intercept, February 6, 2019.

29 Associated Press, "Georgia Nuclear Power Plant Vogtle Rates Costs," AP News, accessed January 23, 2024.

30 International Energy Agency, "Hydropower Essentials," 2022.

Relationship between transmission line length completion time



Via Belfer Center.

Most of this time is spent getting the proper permits. Transmission lines require approval from every state they cross (and, in some states, every county),[31] and states often only consider in-state benefits when making their decision, rather than the benefits to the grid as a whole. This makes it difficult for long-distance transmission lines that don't provide power to the states they cross to secure approval. Transmission lines also need to secure the right to build on every parcel of land that they cross. The Grain Belt Express,[32] a planned transmission line stretching from Kansas to Indiana, needs approval from 1,700 landowners, many of whom are still holding out.

Local residents often oppose new transmission construction, though transmission lines seem especially likely to galvanize opposition. Activists in Maine have spent years opposing the construction of a transmission line that would bring in power from Quebec hydroelectric plants.[33]

Congress tried to address this issue in the 2005 Energy Act, which gave FERC "backstop authority" to approve transmission line construction if states withheld it, so long as the transmission was built in "National Transmission Corridors" designated by the DOE. However, early attempts to use this power were successfully challenged in federal court, and it hasn't been used since.

The difficulty of building transmission lines, in turn, holds back the construction of other electrical infrastructure. In the early stages of a new electricity generation or storage project, an interconnection study is required to determine the effect the project will have on the grid and what additional infrastructure will be needed to accommodate it. In part due to a lack of available transmission infrastructure (DOE 2023), the time it takes to get interconnection approval is increasing — since 2005, it has doubled. There is currently more generation capacity[34] waiting in the interconnection queue than all existing US power plants combined. When plants are authorized to interconnect, they face interconnection costs that are often

31 Center on Global Energy Policy, "Building a New Grid Without New Legislation: A Path to Revitalizing Federal Transmission Authorities," Columbia University.

32 Austin Vernon, "Siting Power Lines," accessed January 23, 2024.

33 Jake Bittle, "Maine Transmission Line: A Key to New England's Clean Energy Future?," Grist, accessed January 23, 2024.

34 Lawrence Berkeley National Laboratory, "Queued Up: Federal, Regional, and State Policies and Practices for Queue Reform," April 6, 2023.

50 to 100% of the cost of the plant itself, due to the need to build additional grid infrastructure to accommodate them.

The lack of sufficient transmission infrastructure also shows up in higher-than-necessary electricity costs. Customers near sources of wind or solar power often enjoy cheaper power than those farther away, because there's insufficient transmission infrastructure to move the cheap power long distances. These "congestion costs" have increased from around $1 billion in 2002[35] (in 2023 dollars) to more than $13 billion in 2021.[36]

To sum up, we're faced with the challenge of rebuilding our electrical grid to use low-carbon sources of electricity. This will require the construction of a large amount of electrical infrastructure, but it's not clear what kind of infrastructure that should be. Historically, economics dictated that power was provided by large, centralized power stations, tied into electrical grids. But many low-carbon electricity technologies, such as wind and solar, have a different set of design constraints. Alternative technologies tend to be early-stage (such as geothermal or nuclear fusion) or have a poor track record of success in the US (such as nuclear).

Given the complexity of this landscape, how should we think about the future of electric power generation?

Hard and Soft Paths Revisited

In 1976, physicist and energy expert Amory Lovins articulated two strategies for the future of US energy. In an article titled "Energy Strategy: The Road Not Taken," Lovins laid out two possible futures for US energy policy: the hard path and the soft path.[37]

The hard path was, in Lovins's words, "an extrapolation of the recent past" — meeting energy needs by constructing large-scale, centralized energy infrastructure (such as large nuclear reactors, coal plants, and high-voltage transmission lines), and weaning off fossil fuels by engaging in large-scale electrification of industry and transportation. This path, claimed Lovins, would only be possible by way of large-scale government intervention, and would require enormous capital investment from utilities. Lovins unenthusiastically describes it as a world of "subsidies, $100-billion bailouts, oligopolies, regulations, nationalization, eminent domain, and corporate statism."

The soft path was to instead transition to smaller-scale energy technologies that were "flexible, resilient, sustainable, and benign" — rooftop solar panels, buildings designed for increased energy efficiency, industrial cogeneration, solar heating and cooling, and energy conservation. By emphasizing local generation, the soft path would eliminate the need for centralized infrastructure, including much of the transmission and distribution system. And it would eliminate the power losses that were an inevitable result of moving electricity long distances, along with the conversion losses from turning fuel into electricity and back into heat.

In many ways, Lovins was describing a very different world than the one we find ourselves in today. Lovins argued for the soft path in part out of environmental concern, but today large-scale electrification of industry and transport is considered the pro-environment path. Similarly, Lovins argued against constructing large nuclear plants and for the adoption of small-scale diesel generators, which would be a strange position for a modern environmentalist to adopt. Solar and wind power, rather than staying small-scale, have been adopted as the large, utility-scale infrastructure that Lovins opposed. Nevertheless, we can still broadly map the energy strategies for tomorrow's grid onto Lovins' dichotomy.

35 U.S. Department of Energy, "National Transmission Grid Study," 2002.

36 Grid Progress, "Transmission Congestion Costs in the US: 2021 Update," April 2023.

37 Amory Lovins, "Energy Strategy: The Road Not Taken," Rocky Mountain Institute, accessed January 23, 2024.

The modern hard path, the "extrapolation of the recent past," is to lean into the strategy of scale that the electric power industry pursued successfully for 70 years, by building large-scale, centralized power stations and moving that power with even more long-distance transmission lines. In essence, the hard path is to make the grid even bigger.

One strategy would be to resume the construction of large nuclear plants that was halted in the 1980s. Though recent construction in the US has resulted in large cost overruns, such plants could be built much more cheaply with proper government support. A report produced by the OECD's Nuclear Energy Agency argued[38] that a government commitment to building a series of standardized plants "is the most promising avenue" for nuclear plant cost reduction. Such commitment would allow taking advantage of learning-by-doing, create a more robust nuclear supply chain (which has atrophied in the US), and allow the spreading of various non-recurring costs (like design approvals). And while historically US nuclear plant costs were driven up by unclear and constantly changing regulatory requirements, a regulatory policy that stabilized requirements could address these issues (For more on how nuclear power might be made cheaper, see "Why Does Nuclear Power Plant Construction Cost So Much?"[39]).

The hard path also means building many more long-distance transmission lines, tying the entire country together in what is sometimes called a macrogrid.[40] More transmission capacity makes it possible to move renewable power long distances, spreading where it gets used. The windiest areas of the country, for instance, are in the Great Plains[41] and off the coast,[42] and the sunniest places are in the Southwest.[43] There's often not enough transmission capacity to move the power they generate to where it can be used.

More transmission lines would also help with grid reliability. By making the grid larger than the weather systems that impact it, power can be supplied from elsewhere, even if weather events cause major generation disruptions. The wide scale outages in Texas during Winter Storm Uri could have been avoided had there been enough transmission capacity to move power from areas outside the storm.

Right now, building these long distance transmission lines is difficult. Clean Line Energy's ambitious attempts to do so have so far failed.[44] Giving FERC the power to designate[45] transmission corridors and issue federal permits could unclog the bottleneck. Currently, utilities are incentivized[46] to build small-scale transmission projects within their own areas of service, rather than focusing on larger regional projects with greater benefits to the grid. Updated FERC rules and an interregional planning process that focused on overall grid benefits could change this situation.

More generally, the hard path requires increasing the scale at which electrical grid planning takes place, and creating the tools for those large-scale plans to be implemented.

The soft path, on the other hand, leans into smaller scale technologies that don't require building centralized power stations and long-distance transmission infrastructure. Encouraging energy conservation and more energy efficient buildings would be a soft path approach.

38 OECD Nuclear Energy Agency, "Unlocking Reductions in the Construction Costs of Nuclear: A Practical Guide for Stakeholders," accessed January 23, 2024.

39 Institute for Progress, "Nuclear Power Plant Construction Costs," accessed January 23, 2024.

40 The Conversation, "The US Needs a Macrogrid to Move Electricity from Areas that Make It to Areas that Need It," March 5, 2021.

41 National Renewable Energy Laboratory, "Cost of Wind Energy Review," 2011.

42 U.S. Energy Information Administration, "DOE Provides Detailed Offshore Wind Resource Maps," last updated February 17, 2021.

43 The State Journal-Register, "Southwest Needs Power Lines to Meet Demand," September 18, 2012.

44 Windpower Monthly, "Ambitious Clean Line Energy Wrapping Up," accessed January 23, 2024.

45 Center on Global Energy Policy, "Building a New Grid Without New Legislation."

46 Utility Dive, "Can FERC Convince Utilities to Build Modern Transmission Systems?," accessed January 23, 2024.

Residential and commercial buildings make up about 40% of total energy use in the US (when losses are included),[47] but adopting energy efficient construction like passive house[48] could reduce energy use by 75 to 80%.[49]

The soft path also includes demand-side management.[50] By shifting when customers use electricity, peaks can be smoothed out, reducing overall electricity demand. Refrigerator and cold-storage warehouse compressors, for instance, use a large amount of energy, but that use can to some extent be shifted by running the compressor at different times, minimizing peak electricity demand. Air conditioner use can likewise be staggered to minimize peaks, including using direct load control, which enables a utility to remotely change a customer's air conditioner temperature settings in times of high demand (in exchange for an annual incentive payment). This summer, Arizona utilities reduced peak demand on the grid by 276 megawatts by raising the temperature settings on the thermostats of more than 100,000 customers.[51]

Similarly, energy storage (either grid scale or via batteries on things like electric vehicles or induction stoves) can dampen the fluctuations from variable sources of energy and demand, requiring less power to be transmitted long distances (though the construction of transmission infrastructure would still be required to connect batteries to the grid).[52] Other soft path strategies include aggressive use of rooftop solar, advanced geothermal, brick thermal storage for process heat,[53] and "microgrids" which can be isolated from the main power grid and thus are less susceptible to cascading failures. Demand-pull mechanisms may also jumpstart long-duration energy storage.[54]

Lovins was unabashedly pro-soft path, and he characterized the paths as mutually exclusive: money spent on one is money not spent on the other. But today, these paths can coexist, and in many ways are complementary. Demand-side management, leveraging electric-vehicle storage, and next-gen geothermal can work hand in hand with the buildout of large transmission lines and mass deployment of solar and wind. Building large-scale nuclear plants doesn't mean we can't also build more energy efficient buildings.

But whatever combination of solutions we choose will require the building of enormous amounts of electrical infrastructure. Saul Griffith estimates that producing all required energy with solar PV would require 15 million acres of solar panels, an amount of land area roughly the size of West Virginia. Producing it with nuclear power would require on the order of 1,000 more large nuclear plants. And whether we build 10-mile transmission lines to connect new power plants to nearby cities, or 1,000-mile transmission lines to move the power across the country, we'll need a lot of them. The REPEAT project estimates[55] that to avoid restricting the growth of solar and wind generated electricity, we'll need to double the recent construction rate of transmission lines.

47 U.S. Energy Information Administration, "How Much Oil is Consumed in the United States?," last updated June 4, 2021.

48 Wikipedia, "Passive House," last modified January 22, 2024.

49 Bloomberg, "Net-Zero Buildings Could Bring an Energy Savings Boom," April 7, 2022.

50 Wikipedia, "Demand Response," last modified January 21, 2024.

51 Canary Media, "Smart Thermostats are Helping Arizona's Grid Ride Out Brutal Heat," accessed January 23, 2024.

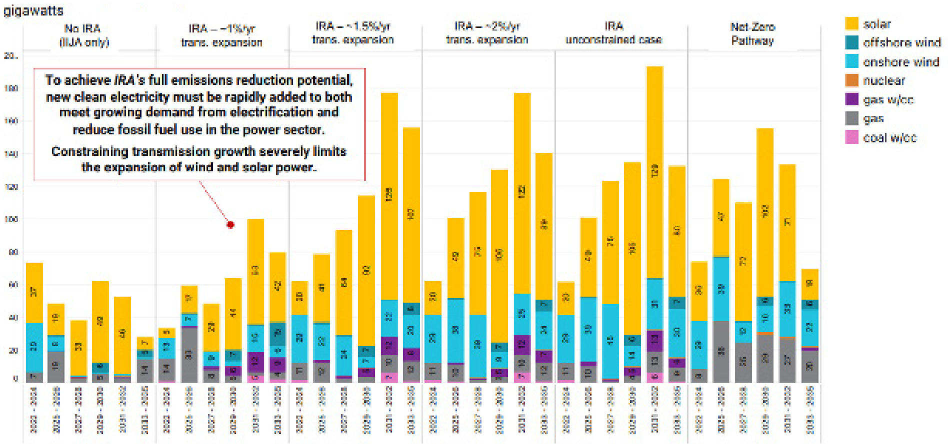
52 Casey Handmer's Blog, "Grid Storage Batteries Will Win," July 12, 2023.

53 Austin Vernon's Blog, "Brick Storage," accessed January 23, 2024.

54 Institute for Progress, "Demand Commitment Mechanisms Can Jumpstart Long-Term Energy Storage," accessed January 23, 2024.

55 REPEAT Project, "Reports," accessed January 23, 2024.

Annual Average Capacity Additions



Via REPEAT.

Thus the overwhelming priority of energy policy must be *making it easier to build things.* Policies that make it easier to build will be necessary, regardless of which combination of solutions ultimately is the most feasible. For mature industries like solar and wind, reforming[56] NEPA and other environmental laws that needlessly slow down building and give niche interests enormous power to delay projects could dramatically accelerate buildout. For more nascent industries, a combination[57] of regulatory reforms and cost-sharing could help bridge the gap to commercialization. We should also reform the interconnection process, so projects don't spend years waiting in queues to be connected to the grid.

If we stay on our current energy trajectory, Americans will pay higher prices for inconsistent energy, while clean projects languish unbuilt. Incremental changes won't change this reality. The good news is that a deal on permitting reform can have genuine bipartisan appeal. For example, an expansive deal could reform laws like NEPA to maintain good-faith lawsuits but block off obstructionists and pair it with substantive transmission reform to streamline permitting wait times, accelerate clean energy deployment, and improve grid reliability. Such a deal is possible,[58] if both sides prioritize an abundant energy future for Americans.

56 Institute for Progress, "Environmental Review," accessed January 23, 2024.

57 Employ America, "Hot Rocks Part Four," January 2024.

58 Institute for Progress, "A Grand Bargain for Permitting Reform," accessed January 23, 2024.