Overloads – Yesterday's and Today's

By John Benson

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1. Introduction

Most of my readers know that I live in California in the United States (hereafter, "U.S."). The U.S. and especially California has a very dynamic economy, that is also growing very rapidly. This has led many energy professionals to wonder if we will "run out of energy." That is, will our existing energy organization be unable to keep up with ever-expanding economy? Good question, but the good news is that our energy infrastructure is an integral part of our economy, and is being driven by the same market forces as our economy in general, and thus it probably will keep up.

Also, I came across two excellent articles in two periodicals that I subscribe to that, that double down (triple-down?) on my conclusion at the end of the above paragraph. This is the subject of this paper. Section 2 looks back to earlier examples, and section 3 looks at the present and future prospects for the energy industry to keep pace. Section 4 looks at some challenges in meeting the increased demand of data centers.

2. Yesterday's

The world is collectively freaking out about the growth of artificial intelligence (AI) and its strain on power grids. But a look back at electricity load growth in the United States over the past 75 years shows that innovations in efficiency continually compensate for relentless technological progress.[1]

In the 1950s for example, rural America electrified, the industrial sector boomed and homeowners rapidly accumulated nifty electric appliances such as spinning clothes dryers and deep freezers. This caused electricity demand to grow at a breathtaking clip of nearly 9 percent per year on average. The growth continued into the 1960s as homes and business readily adopted air conditioners, and the industrial sector automated. But over the next 30 years industrial processes such as steelmaking became more efficient, and home appliances did more with less power.

Around 2000, the onslaught of computing brought widespread concerns about electricity demand. But even with the explosion of Internet use and credit card transactions, improvements in computing and industrial efficiencies and the adoption of (first florescent and then) LED lighting compensated. Net result: average electricity growth in the U.S. remained nearly flat from 2000 to 2020.

Now it's back on the rise, driven by AI data centers and manufacturing of batteries and semiconductor chips. Electricity demand is expected to grow more than three-percent every year for the next five years, according to GridStrategies, an energy research firm in Washington DC. "Three percent per year today is more challenging than 3% in the 1960s because the baseline is so much larger." Says John Wilson, an energy regulation expert at GridStrategies.

Can the U.S counter the growth with innovation in data center and industrial efficiency? History suggests it can.

[1] IEEE Spectrum, May 2025 Issue, Page 14, "The Data. Putting AI's Energy Use in Context"

3. Future

There are two potential pathways for meeting future exploding energy-demand growth like that of our artificial intelligence (AI) and crypto sectors: increased energy-efficiency and increased energy production. One problem with the “production” is that we are starting to see the first serious consequences of climate change, and this is heavily driven by the use of fossil-fuels (including natural gas) to generate electricity, which is our main energy-carrier. We are already evolving electricity-production from greenhouse gas (GHG) generating methods to renewable (mainly solar and wind) and other very-low GHG (like nuclear and hydro) methods. But all this means is that we need to balance these two demands (generate more electricity and reduce that electricity’s GHG-intensity), which I believe we are doing.

The two subsections below will look at these two demands.

3.1. Efficiency

In the beginning of section 3 we pointed out that *“…exploding energy-demand growth like that of our artificial intelligence (AI) and crypto sectors…”* are the primary applications driving the current demand growth. In reality, these two applications are really just two different flavors of the same Kool-Aid: analytical computation. Thus, any techniques that work to increase the efficiency of implementing one will probably also work for the other.

The good news for your author is that I recently came across a good article on more energy-efficient implementation of AI. Excerpts from this are below.

Artificial Intelligence is everywhere: it's designing new proteins, answering Internet search questions, even running barbecues. Investors are captivated by it-and so is the U.S. president. Just after taking office, President Donald Trump announced his support for Stargate, a company worth up to $500 billion, bankrolled by some of the biggest players in this space, to facilitate AI development in the U.S.[2]

But the data centers and other infrastructure needed to develop and run the technology are incredible electricity hogs. And with Trump's declaration of a "national energy emergency" -an undisguised ploy to increase fossil-fuel production -AI' s energy needs are poised to make climate change even worse. The technology is already responsible for massive greenhouse gas emissions that cause climate change. If Stargate and the many other companies developing AI platforms do not insist on cleaner and more efficient energy, they will only aid in the destruction of our planet.

Author’s comment: The only way out of the disaster described in the last sentence above is to develop near-zero-GHG electricity sources in lockstep with the increasing demand, plus a margin to slowly retire existing GHG-producing generation. This will be explored in the next subsection.

This technology's many flavors include the buzzy generative AI, the basis of ChatGPT and Google's year-old search-answer system. During its operation, generative AI guzzles electricity in two stages, requiring warehouse-size data centers to house the necessary computing.

[2] The Editors, Scientific American, April 2025 Issue (hardcopy), pages 70 & 71. To Order a Copy of a Scientific American Issue: Call (800) 333-1199.

Developers must first train the AI model on vast stores of data, which takes countless hours and requires enormous computing capabilities. Training one ChatGPT precursor consumed enough electricity to power 120 average U.S. homes for a year. Every time a model is upgraded, it must be retrained. The sudden release of the DeepSeek chatbot out of China-reportedly trained for a fraction of the price of ChatGPT and similar U.S. systems-may lead to less energy-intensive processes, but it's too soon to know for sure.

And the demand doesn't stop once a model is trained. Each query the AI receives requires it to consider everything it has been fed, then synthesize an answer from scratch in a process called inference, which also requires energy. Compared with search engines, text-generating systems can easily use 10 times as much energy to address a query, and sometimes they use dozens of times more. Image generation requires even more energy-as much as 50 percent of the amount needed to fully charge a smartphone, one study found.

Many analyses interpret this energy use for the training and large-scale operation of AI as an increased cost to the system's owner. For example, one estimate suggests that if Google uses generative AI to produce 50 words of text per answer in response to just half of the queries it receives, it will cost the company some $6 billion.

But the truth is, we all will have to pay when this exorbitant energy use inflates the cost of the kilowatt, regardless of our personal interaction with the technology. The scale of consumption is simply too large, and as AI sneaks into ever more aspects of daily life, its energy use is projected to skyrocket. At the industry scale, it's difficult to isolate AI from other computing demands, but data centers serve as a convenient proxy, given that the rise of the technology has led to their boom…

3.2. Increased Very Low GHG Electricity

We don't need to depend on fossil fuels to power our homes. We can harness the energy of the wind and sun—and the good news is that we're doing a lot more of that.[3]

Wind and solar produced enough energy to power more than 60 million homes in 2023. That's equivalent to more than 40% of the homes in the entire United States! We're rapidly approaching the point where enough renewable energy could be produced to power more than half of our homes.

Enough wind power was produced to fuel 39 million homes. The amount of power we harness from wind has more than doubled in the last decade.

Enough solar power was produced to fuel 22 million homes. That's more than eight times as much compared to 2014!

Both the raw amount of renewable energy available, and the speed of its growth, are increasing. Renewable energy has grown over the last 10 years in every U.S. state.

3.2.1. We have more battery storage capability than ever before

Battery storage is a key component of a sustainable renewable energy system because many renewable energy sources are "intermittent," meaning they don't generate power all the time. Batteries allow you to store energy generated by the sun during the day or from the wind while it's blowing, and then use that energy at night or when the wind is still.

[3] Environment America, "Good news for our climate: Renewable energy is on the rise," November 4, 2024, https://environmentamerica.org/articles/good-news-for-our-climate-renewable-energy-is-on-the-rise/

Delivering the energy we need in emergencies or on a still day or night doesn't have to mean firing up more greenhouse gas polluting power sources. It can just require flipping a switch.

America has almost 100 times the battery energy-storage capability than it did in 2014. This incredible growth is part of the key to unlocking our ability to use renewable energy to power our everyday needs.

Batteries are also vital sources of power during times when the main power grid is stressed or unavailable, like during extreme weather events. EV owners can already use their cars – essentially batteries on wheels – to keep devices charged during power outages. It may someday be possible to use an electric car to power your home during an outage, too.

Home batteries built for the purpose of storing renewable energy are already a reality, too.

America had 15.5 gigawatts of battery energy storage at the end of 2023, 97 times as much as in 2014 and 72 percent more than at the end of 2022. There's room to grow, but this explosion of storage capability is a very promising start!

Author's comments: I have a small (10 kWh) battery energy storage system in my house in addition to a solar roof. Also, battery-energy storage systems (BESS) are not the only game in town.

3.2.2. Pumped Storage

Also, there are seven hydroelectric pumped storage facilities in California. A table listing these is below.[4] Each typically has at least twice the run-time as a BESS.

Current California Hydropower Pumped Storage Facilities

Name	Location	Coordinates	Capacity (MW)	Owner	Year	Ref
Castaic	Los Angeles County	34°35′15″N 118°39′24″W	1,500	CDWR, LADWP	1973	[143]
Helms	Fresno County	37°02′21″N 118°57′49″W	1,212	PG&E	1984	[144]
J.S. Eastwood	Fresno County	37°08′52″N 119°15′24″W	200	SCE	1987	[145][146]
Lake Hodges	San Diego County	33°03′29″N 117°07′08″W	42	SDCWA	2012	[147]
O'Neill	Merced County	37°05′55″N 121°02′52″W	25	USBR	1967	[148]
Thermalito	Thermalito	39°30′55″N 121°37′45″W	120	CDWR	1968	[149]
William R. Gianelli	Merced County	37°04′07″N 121°04′48″W	424	CDWR, USBR	1968	[150]

[4] https://en.wikipedia.org/wiki/List_of_power_stations_in_California

3.3. Numbers of Electric Vehicles (EVs) Expand Rapidly

Author's comment: EV's are not just good for the typical commuter's pocketbook, they are also good for the grid. Typical EVs purchased today, like the Tesla Model 3 and Model Y, have, respectively, 272 miles, and 311 miles of range on a full standard battery charge. This means that smart EV owners will charge their EVs at home during the lowest demand period (typically late night and very early morning hours). Since this is the period where the grid has the least demand, it is also the grid is unlikely to be stressed.

At the end of 2023, at least 3.3 million electric vehicles were on American roads. That represents a 25-fold increase from 2014 and explosive growth over the course of just a decade.[3]

The transportation sector is the single largest source of U.S. greenhouse gas emissions. Plus, more than half of the emissions from transportation are from light-duty vehicles – like our personal cars. That means switching to more EVs is one of the most important ways we can reduce our contribution to the climate crisis.

One of the reasons switching to an electric vehicle might seem tricky is because you need places to charge it – but keeping your EV fueled up is also easier than ever nowadays. As of the end of last year, there were more than 176,000 electric vehicle charging stations nationwide, with more being built all the time.

4. On the Other Hand

US utilities have been caught flat-footed as a surge in the development of power-hungry data centers and manufacturing facilities has packed load interconnection queues. As we wrote in last October's Horizons, this has left the power sector with a demand growth dilemma. And the challenge has only intensified.[5]

There are substantial hurdles to meeting such gargantuan demand growth: procurement bottlenecks for critical supply-side equipment, the retirement of substantial amounts of coal-fired generation, tariff and energy policy changes that make renewables development more challenging, long lead times on new projects and the need for transmission upgrades.

Since October, the long load queues have grown even longer. Wait times for grid connection have increased. Developers and data center owners were hoping they could find off-grid solutions to circumvent delays only to come up against technical issues.

It is increasingly clear that some vertically integrated regulated utilities are best placed to supply the new demand. Areas with retail choice that rely on competitive power markets to meet demand growth are finding it harder.

[5] Chris Seiple, Ben Hertz-Shargel, Wood Mackenzie,"US power struggle How data center demand is challenging the electricity market model," June 2025, https://www.woodmac.com/horizons/us-data-centre-power-demand-challenges-electricity-market-model/?__FormGuid=737fa606-1f5f-4489-aec9-6b139fc288f7&__FormLanguage=en&__FormSubmissionId=302d3039-1158-4a3e-b976-cef6025b66ee

These issues are of paramount importance. The large-load demand being met by regulated utilities is raising a host of new issues for regulators and could leave existing customers picking up the tab for data center power investments, should demand not materialize as anticipated. In some cases, just a few major customers will soon account for as much utility infrastructure investment as all other customers put together, reshaping utilities' risk profile. In a competitive power market, if data centers are added faster than new power plants can be brought online, it could threaten grid reliability and lead to power outages.

4.1. Growth of Data Centers

The biggest challenge for the power industry is predicting the future scale of data center electricity demand. In a fundamental mismatch, the tech companies fueling the surge only have demand visibility for three to five years, whereas energy-sector investors take a 30-year view. Moreover, the profitability of new investments in artificial intelligence (AI) services, in particular, is unknown. As tech companies gain greater understanding of the AI profit outlook, there could be big upward or downward shifts in their needs.

Wood Mackenzie is now (June 2025) tracking 134 GW of proposed data centers across the US, up from 50 GW a year ago. Grid operators have received interconnection requests far exceeding this, as some developers have bagged spots in multiple queues, hoping one of them will pay off, while others have yet to disclose project details. As the ability to secure interconnection and energy supply becomes the biggest constraint on data center developers, proposed project locations are extending beyond traditional markets into states such as Pennsylvania, Ohio, Indiana and Iowa, where large-scale data center construction is a new phenomenon.

4.2. Public Commitments

A number of US utilities have publicly reported how much data center capacity they have signed up to serve – and this is the strongest indicator we have of the scale of coming demand growth. To date, these utilities have committed to supplying 64 GW of new data center capacity, equal to a 12% increase in current US electricity demand.

These utilities have an additional 132 GW in their large-load interconnection queues to which they or the developer have not yet committed. Another five utilities have not disclosed their commitments but have indicated that they have 188 GW in their queues. Much of this capacity is with Oncor in Texas.

Most of the utilities that have reported commitments are in states that lack retail choice, meaning that a utility committing to serve such a load must ensure it has adequate power supply and transmission to do so. Among the utilities that have reported commitments to serve data centers, Exelon and AEP-TX cannot own generation, and so have committed only to making the transmission upgrades required to accommodate the large load. It is up to the competitive market to ensure there is generation supply to meet the load.

4.3. Off-Grid Solutions?

With interconnection being the main choke point for new data centers, industry attention has focused on developing off-grid solutions. These are self-sufficient power systems – directly connected power plants or renewable resources – that operate independently of the main electrical grid. Some projects aim to be 'bridge solutions' until a grid interconnection is established, and some are intended as long-term solutions. But while there is much industry chatter about such off-grid solutions, they are extremely rare in our project tracking.

Off-grid projects face one key obstacle. Data center firms are good at building facilities that serve their computing needs and consume a large amount of power. Their demand can vary from minute to minute, however, and a grid is better suited than most other options to dealing with such fluctuating demand. Relying on resources with no grid connection introduces enormous engineering complexity and risk, for which data centers have limited appetite.

There are multiple obstacles beyond the engineering complexity and cost of meeting minute-to-minute fluctuating demand. A key one is getting companies to align on commercial terms: electric generation developers typically want a 20- to 30-year commitment to undertake such projects, but data center developers tend to think in terms of much shorter timeframes. Having adequate land for data center development and generation is another, as is securing air permits that allow onsite generators to run a sufficient number of hours to provide the needed level of reliability.

Author's comment: In the subject covered by the above paragraph, there are multiple alternatives for on-site generation, but the two most popular are natural gas fired generators (internal combustion, combustion turbine or fuel cells) and photovoltaic (PV) generators. The former can track load 24 x 7, but has a higher on-going cost (for fuel and maintenance) and the latter has a higher land cost. Battery energy storage systems can be used to mitigate PV's intermittency, but these are pretty expensive.

Despite these obstacles, a few developers continue to work on off-grid solutions. One example is AEP's use of natural gas fuel cells combined with ultracapacitors, intended to serve as a bridge solution until it can connect the data center to the grid.

4.4. Regulated Utilities Best Solution

With off-grid unlikely to be a viable, scalable solution, it is increasingly clear that vertically integrated regulated utilities that embrace data centers are the likely leaders in capturing the growth opportunity. They can capitalize on the following strengths:

- *Integrated load and generation planning processes. Thanks to their integrated planning processes, regulated utilities are in the best position to plan for new demand growth. A data center developer knows that when it has a utility's commitment for an interconnection, it will be able to secure power supply.*

- *Flexibility and creativity in accelerating project timelines. Utilities are not known for innovation, but because of their integrated planning processes, they are best placed to advise data center developers on how to shorten development timelines. Among the critical factors that can accelerate projects are the ability to interrupt schedules, alternative project sizing, utilizing grid enhancing technologies, differing ramp schedules, creative power contracts or other out-of-the-box options. They can also advise the data center on where it should connect.*
- *Building local buy-in. Utilities' political relationships can be helpful in gaining local support for data center development and paving the way for zoning or regulatory changes. One data center firm told us they look for energy suppliers that will "foster political and public alignment around data centers" and "enable data centers in site development plans and zoning".*
- *Land ownership at attractive sites. Multiple utilities that have retired coal-fired power plants or other economic development sites have realized that they own land with significant transmission and fiber infrastructure, where data centers could be sited.*

Utilities' embrace of large loads differ dramatically. Many see them as an opportunity to expand their rate base, to improve existing infrastructure utilization and to support local economic development. Some, however, want nothing to do with large-load growth. In some cases, regulatory rules mean data centers offer utilities few benefits. Others are struggling to get workers to embrace innovative interconnection processes or to move at the kind of speed preferred by data center developers.

Still, a few utilities are emerging as winners as they gain commitments to sign data centers and expand their growth opportunities. Several say data centers have enabled them to increase asset utilization and reduce costs for existing customers – although there are limits to these benefits, as further demand growth will require considerable new investment. One utility has a unique tariff structure whereby, if it is able to charge a large-load customer more than the cost of serving it, it shares a portion of the profit with customers, and the remainder enables it to earn more than its regulated return on equity.

Not every utility is a winner, however. While some of the utilities we talked to want to build new generation capacity themselves and increase their rate base, others do not have the balance-sheet scope to do so, may have unique regulatory rules that result in new load not providing much benefit, or face regulatory processes that require competitive power providers to meet the new demand. This will create opportunity for competitive power providers to negotiate new power purchase agreements with utilities or to sell their development sites to utilities.

Author's comment: Reference 5 did a very deep dive into the problems and potential solutions with large-load utility customers like large data centers. However, I decided to limit my content from this source. For readers that are interested in seeing more, go through this reference. You will probably need to register to see the whole article (I did). Hopefully, Wood Mackenzie will not spam us too heavily. Some spam from WM would be well-received by your author, as this consultant focuses on important issues.

5. Late Breaking News

The post summarized and linked below just came over the web (two days before this paper is due to be posted). This is strongly relevant to this post, so I decided to include it.

"Last year, California added a record amount of clean energy – bringing our total new capacity to over 25,000 megawatts in just five years. We've never added so much capacity to our grid in such a short amount of time, transforming our power grid to be cleaner and more reliable and resilient than ever before."[6]

- *Governor Gavin Newsom*

In 2024 alone, California added approximately 7,000 megawatts (MW) of new clean energy nameplate capacity —representing the largest single-year increase in clean energy capacity added to the grid in state history. This new figure broke the previous records set in both 2022 and 2023, marking a third consecutive year of unprecedented clean energy growth.

"California has set ambitious clean energy goals, and utilities and community choice aggregators have stepped up to deliver clean resources to communities up and down the state," said California Public Utilities Commission President Alice Reynolds. "We are bringing renewable energy online at an unprecedented scale and pace never seen before."

This rapid expansion of clean energy capacity is the result of procurement orders from the California Public Utilities Commission (CPUC) aimed at bolstering grid reliability while advancing the state's clean energy targets and meeting Renewables Portfolio Standard (RPS) requirements.

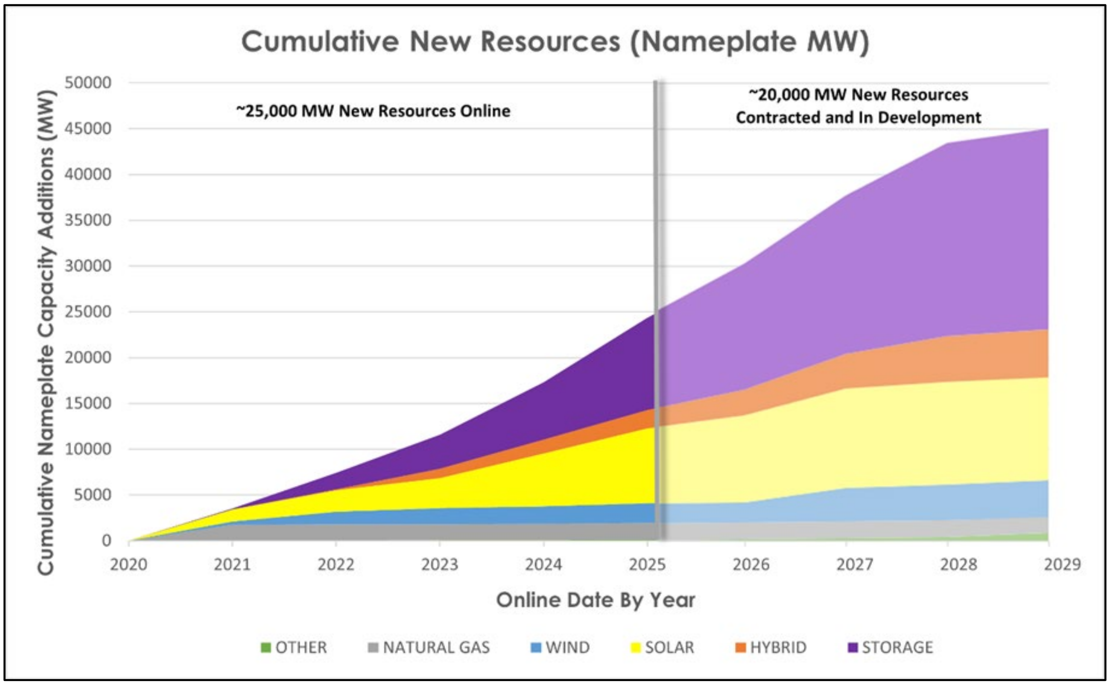
Building energy infrastructure is a key part of the Governor's build more, faster agenda delivering infrastructure upgrades and thousands of jobs across the state.

5.1. On track for further clean energy expansion

More than 75,000 MW of new clean energy capacity is expected to come online by 2040. To make this vision a reality, California's electric grid will continue to evolve to unlock access to new clean energy capacity and power. At the same time, utilities and community choice aggregators are actively contracting with projects that can be built using existing electric infrastructure, helping accelerate the pace of development, at least cost to customers.

[6] California Governor Gavin Newsom, "New data shows California is adding more clean energy capacity to the grid faster than ever before," June 4, 2025, https://www.gov.ca.gov/2025/06/04/new-data-shows-california-is-adding-more-clean-energy-capacity-to-the-grid-faster-than-ever-before/?utm_source=newsletter&utm_medium=email&utm_campaign=currentclimate&cdlcid=628673ca6e1a1d1211f1d747&section=

Currently, more than 20,000 MW of clean energy projects are already under contract and in development to serve California customers by 2030.



5.2. California's climate leadership

Pollution is down and the economy is up. Greenhouse gas emissions in California are down 20% since 2000 – even as the state's GDP increased 78% in that same time period.

The state continues to set clean energy records. Last year, California ran on 100% clean electricity for the equivalent of 51 days – with the grid running on 100% clean energy for some period three out of every five days. Since the beginning of the Newsom Administration, battery storage is up to over 15,000 megawatts – a 1,944% increase.

6. Other Recent Facts

There are some facts about renewables that I've known for some time, but only recently come across strong evidence for:

Unsubsidized Wind & Solar Lowest Cost Generation Sources for Last 10 Years: *Despite facing macro challenges and headwinds, utility-scale solar and onshore wind remain the most cost-effective forms of new-build energy generation on an unsubsidized basis (i.e., without tax subsidies). As such, renewable energy will continue to play a key role in the buildout of new power generation in the U.S. as the lowest-cost and quickest to-deploy generation.*[7]

[7] Lazard Releases 2025 Levelized Cost of Energy Report, https://www.lazard.com/media/0sopmth5/lazard-releases-2025-levelized-cost-of-energyplus-report.pdf

Increased Cost of Gas-Fired Generation: Gas-Fired Generation Reaches 10-Year High LCOE: *While persistent low gas prices, high energy demand and increasing renewable LCOEs have resulted in the continued cost competitiveness of operating existing baseload gas generation, the cost of building a new combined cycle gas turbine has reached a 10-year high. Turbine shortages, rising costs and long delivery times are expected to continue driving steep LCOE increases for gas technologies in the near term—however, productivity enhancements and supply chain normalization could offset such increases over the longer term.*

Budgetary Risks from Projects:

In a new state-of-the-art study, published in the journal Energy Research & Social Science, researchers at the Boston University Institute for Global Sustainability (IGS) found that runaway construction costs and delayed timelines stymie many energy projects. In fact, the average project costs 40% more than expected for construction and takes almost two years longer than planned, as the study showed.[8]

Nuclear power plants are the worst offenders, with an average construction cost overrun typically twice as much as expected or more, and the most extreme time delays. To be exact, the average nuclear power plant has a construction cost overrun of 102.5% and ends up costing $1.56 billion more than expected.

Looking at newer net-zero options reveals higher risk as well. Hydrogen infrastructure and carbon capture and storage both exhibit significant average time and cost overruns for construction, along with thermal power plants relying on natural gas, calling into question whether these can be scaled up quickly to meet emission reduction goals for climate mitigation.

"Worryingly, these findings raise a legitimate red flag concerning efforts to substantially push forward a hydrogen economy," says Benjamin Sovacool, lead and first author of the study, director of IGS, and professor of earth and environment.

By contrast, solar energy and electricity grid transmission projects have the best construction track record and are often completed ahead of schedule or below expected cost. Wind farms also performed favorably in the financial risk assessment…

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[8] Laura Hurley, Boston University Institute for Global Sustainability, "Investment Risk for Energy Infrastructure Construction Is Highest for Nuclear Power Plants, Lowest for Solar," May 2025, https://www.bu.edu/igs/2025/05/19/investment-risk-for-energy-infrastructure-construction-is-highest-for-nuclear-power-plants-lowest-for-solar/?utm_source=newsletter&utm_medium=email&utm_campaign=currentclimate&cdlcid=628673ca6e1a1d1211f1d747&section=