The role of clean firm generation in an affordable, reliable, and decarbonized grid

The challenge

As energy affordability and data center electricity demand dominate headlines, the challenge of building an affordable, reliable, and abundant clean energy future has never been more important. Decarbonizing the power system at minimum cost will depend not only on scaling renewables, storage, and demand-side solutions, but also on deploying clean electricity technologies with complementary capabilities. Much like a well-balanced investment portfolio, a diversified technology mix offers advantages over long time horizons. One category of clean energy technologies with significant untapped potential, and the focus of this brief, is "clean firm generation" — dispatchable, low-emission electricity generation sources that do not rely on the weather for fuel.

What is clean firm generation?

"Clean firm generation" has been used to refer to low-carbon emission electricity generation sources that are fully dispatchable on demand and that do not rely on weather for fuel to produce electricity at an individual asset level. Reports have included in this category sources such as geothermal, nuclear fission and fusion, fossil with high levels of carbon capture and upstream methane mitigation, and biomass or clean synthetic fuel combustion with sustainable low-emission fuel sourcing (e.g., low-carbon hydrogen).. These technologies look very different from each other, but they share one defining trait: they can deliver low-carbon power whenever it's needed, for as long as it's needed.

Commercial readiness varies widely across these technologies. Existing nuclear and next-generation geothermal are technically demonstrated at or near commercial scale but face cost, supply chain, and financing barriers. Proven technologies like advanced nuclear, carbon capture, and clean hydrogen combustion would benefit from further investment.

Clean firm generation's benefits

Reduced infrastructure buildout needs for decarbonization

Energy system modeling suggests that the inclusion of clean firm generation technologies in power systems will substantially reduce the scale of infrastructure buildout needed to meet growing electricity demand and decarbonize relative to systems without clean firm generation technologies. These technologies cut down the total amount of generation, storage, and transmission infrastructure needed to achieve clean energy goals. This means less land disturbed, fewer raw materials consumed, and less strain on critical mineral supply chains.

There are many reasons behind clean firm generation's infrastructure-related benefits.

- They simply run more of the time – typically 50-100% of hours, compared to 20-50% for wind and solar – so it takes less installed capacity to generate the same amount of electricity, particularly without well-commercialized energy storage.
- They generally require less new transmission build because clean firm resources are large, centralized facilities, rather than multiple, smaller resources.
- They reduce the amount of variable renewable and storage capacity needed to ensure reliability in a decarbonized grid, because clean firm power is available on demand year-round. Without an enormous amount of storage, a variable-renewables-only grid would have a large amount of oversupply during good weather, which utilities often can't use and, without longer-duration storage available, have to curtail or purposefully shut down. Adding clean firm generation to the mix

changes the math substantially. In scenarios with high clean electricity targets, every gigawatt of clean firm capacity can offset 5 gigawatts or more of wind, solar, and storage that would otherwise be needed to cover the same gap.

Reduced decarbonization costs

A key benefit of introducing clean firm generation technologies into power system decarbonization is cost savings. Studies have consistently shown that these solutions alongside additional wind, solar, storage, and transmission can reduce the total system cost and infrastructure requirements of deeply decarbonizing power systems relative to scenarios without clean firm generation technologies. Without clean firm, a decarbonized grid needs a large amount of extra renewable and storage capacity to ensure reliability during periods with the lowest wind and solar output, capacity that must be built, financed, and maintained. This is why decarbonization scenarios that rely only on variable renewables and storage come out to be much more expensive, even when accounting for future technology cost declines.

Clean firm generation typically costs more per unit of electricity than wind or solar, when measured in isolation. But once you zoom out and look at the impacts that clean firm generation has on the whole system and not just the price of individual power plants, clean firm generation can substantially lower what decarbonization costs ratepayers. In this case, the cheapest components don't necessarily add up to the cheapest system over the long term. Notably, clean firm generation technologies' ability to generate at any moment makes it a suitable solution to reducing the output of and/or retiring current fossil fuel power plants.

Increased decarbonization speed and resiliency via technology diversity

Clean firm generation technologies can act as key enablers of risk-resilient decarbonization. The path to a cleaner grid is subject to many risks that may limit progress, including siting and permitting barriers, interconnection queue delays, supply chain constraints, geopolitical shocks affecting critical minerals and equipment, technology cost trajectories that don't play out as modeled, and demand growth that outpaces current forecasts. Clean firm generation technologies present policymakers with additional solutions to reduce uncertainty and mitigate these risks.

Clean firm generation makes the whole electricity system more resilient in the following ways:

- **Spreads out supply chain risk.** Relying on a mix of technologies, each with its own manufacturing and resource needs, means a disruption to any single supply chain doesn't threaten the entire system.
- **Takes up less land.** Per unit of energy delivered, clean firm resources generally have a smaller physical footprint, which reduces the total land needed, could lessen the absolute number of siting, permitting, and environmental review processes, and require fewer communities to host energy infrastructure.
- **Eases the transmission burden.** Because some clean firm generation plants can be sited more flexibly and make fuller use of the transmission lines they connect to, less new transmission is required to achieve decarbonization relative to systems without clean firm generation.
- **Concentrates local economic benefits.** Clean firm projects that conduct significant and extensive community engagement and understand community needs can bring a dense cluster of local jobs and economic activity to the communities that host them. Positive development experiences can build more support over time for these projects.
- **Reduces dependence on critical minerals and exposure to global commodity swings.** Some clean firm technologies need far smaller quantities of critical minerals than renewables and batteries do, which softens exposure to the supply chain and trade tensions surrounding those materials at a system level. Lower reliance on globally traded raw materials means less vulnerability to price spikes or shortages triggered by conflicts or trade disruptions elsewhere in the world.

Policies to support clean firm generation deployment

Despite these benefits, clean firm generation technologies often face an uneven playing field. Some clean energy incentive programs simply exclude them, and some jurisdictions ban certain clean firm generation technologies outright. Emerging technologies face additional headwinds: high early-stage costs, policy uncertainty, and grid planning processes that weren't designed with clean firm generation in mind.

This creates a frustrating cycle where limited deployment slows technological progress, keeps investors wary, limits financing, and then further limits deployment. Breaking that cycle likely requires two parallel policy efforts: near-term support to help these technologies commercialize and bring down costs, and longer-term planning that integrates them properly into how grids are built and operated.

Policy levers to encourage clean firm deployment

There is no single silver-bullet policy to enable clean firm's deployment. Instead, Clean Air Task Force has developed a list of "policy levers" for policymakers to consider:

- **Fund early-stage research and development.** Support for pre-commercial research, development, and demonstration improves technology performance and cuts costs.
- **Provide direct investment for early demonstration projects.** Grants and loans aimed at pilot and demonstration facilities help overcome financing challenges.
- **Offer indirect investment incentives.** Production or investment tax credits, or carbon pricing, help clean technologies overcome the cost premium they carry compared to fossil alternatives.
- **Use direct government procurement.** Government purchases of power or equipment can coordinate and de-risk investment.
- **Build workforce development programs.** Training and retraining local workers for these new industries ensures communities hosting clean firm projects actually benefit from the jobs they create.
- **Adopt technology-neutral clean energy standards.** Letting any low-carbon source qualify, not just renewables, ensures clean firm options aren't structurally locked out. Several U.S. states already use standards like this.
- **Add reliability-focused clean targets.** Layered on top of standard energy targets, these specifically reward the reliability value clean firm power provides.
- **Use technology-specific carve-outs.** Dedicated targets, like California's geothermal targets, give emerging technologies focused support to reach commercial maturity.
- **Put cost and performance backstops in place.** When government absorbs some of the risk of cost overruns, it becomes easier for regulators to approve a project in the first place.
- **Plan regional infrastructure ahead of need.** Proactively building the transmission lines or CO2 transport and storage systems that clean firm projects depend on keeps that infrastructure from becoming the bottleneck.
- **Repeal outright technology bans.** Illinois's 2025 repeal of its partial nuclear moratorium is an example of clearing this kind of obstacle.
- **Offer customer-choice utility tariffs.** Letting customers in regulated utility territories opt to fund specific clean firm projects directly, as Nevada's Clean Transition Tariff does, helps get early projects built even before they're fully cost-competitive.

To achieve decarbonization targets at minimum costs, clean firm generation technologies will need to be advanced in parallel with significant solar, wind, storage, transmission, and demand-side solutions. A power grid built on a mix of complementary clean technologies is more resilient and, over the long run, cheaper than one that leans on a single approach.