Testimony of
Mark P. Mills
Senior Fellow, Manhattan Institute
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"*Keeping the Lights On: Strategies for Grid Resilience and Reliability*"

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Good afternoon. Thank you for the opportunity to testify. I'm a Senior Fellow at the Manhattan Institute where I focus on science, technology, and energy issues. I am also a Faculty Fellow at the McCormick School of Engineering at Northwestern University where my focus is on supply chain systems and future manufacturing technologies. And, for the record, I'm a strategic partner in a venture fund focused on software in energy markets.

The focus of this hearing comes at an important time. Electricity systems are the most important infrastructures of a modern society. We use the euphemism of "keeping the lights on" because everyone knows that it's about far more than that. It's about water pumps and gasoline pumps as well as EV charging stations, and it's about both home furnaces and steel furnaces, refrigerators for vaccines hospitals and food in homes, and, critically, it's about the internet and Cloud networks that businesses of all kinds and sizes, not just citizens, increasingly depend on. The long-run electrification of society has been underway for over a century. and it is far from over.

Ensuring grid reliability and resilience requires dealing with the challenges of meeting both expected and unexpected peaks in demand that are a normal feature of society, while using electricity-producing machines that are episodically unavailable. Thus, the key issue for planners is in ensuring that power is always available to be "dispatched" when needed, and for the length of time needed. Today, the eight major grids that supply America have, collectively, hundreds of thousands of megawatts of 'excess' conventional generation—i.e., more than is needed most of the time—that can be dispatched when needed to fill gaps created by outages from machine failures or weather, or to meet unexpected peaks.

There are three important differences between America's grids today and in earlier decades. First, as EIA data shows and may in fact understate, overall grid reliability has been degrading; put inversely, outages have been increasing. Second, the average retail cost of electricity has been increasing for two decades, up 50% since the year 2000, after earlier declining for several decades. And third, there is now a significant share, almost 12%, of the primary electricity supply that *cannot* be dispatched when needed; that is of course the supply from wind and solar.

Setting aside state and federal policies intended to induce or require greater use of solar and wind, the fact is those technologies are now far cheaper and more useful than at any time in history and thus can now have a substantial role in the nation's energy mix. The key issue going forward is in how reliability—in particular dispatchability—can be maintained at prices consumers are willing to pay as more solar and wind systems are added.

Since sunlight and wind are, by definition, impossible to dispatch at will, the obvious critical issue is in how to fill gaps of unavailability. There are only two ways to do so: maintain or build additional conventional, dispatchable back-up capacity, or built lots of electricity storage. The amount and costs of the latter is almost entirely determined by the nature of nature.

The central challenge isn't so much the oft-noted diurnal variability of sunlight and wind. Rather, it's with two other features of nature. One is the seasonal variability of the wind and sun. The overfall amount of either can be 50%, or more, less in the off season, depending on geography. The other is the regular occurrence of days-long "droughts" of no wind or sun. Such multi-day weather events can be continent-wide (as Europe recently experienced). Meteorological history shows that while such episodes are inherently unpredictable in terms of exactly *when* they occur, it is entirely predictable that they *will* occur, and frequently, over the decades that grid equipment is built to operate. The adage that it's always sunny or windy somewhere in the country is simply not true over decadal periods. That reality, by the way, novates the benefit of building more transmission lines to use solar or wind installations elsewhere as backup.

Thus far, the primary means to ensure grid reliability as the solar/wind share rises could be called the German solution, which is, in effect, to build two grids; one based on solar and wind, and the other with conventional generation to serve, in effect, as the backup. The expense of such a solution is not born by the builders of the solar and wind machines, but by ratepayers. That approach is one reason that the average German residential customer pays about 300% more for electricity than the average in America. However, as Europe has discovered during this past winter when an (inevitable) extended wind drought happened, the dual-grid option exposed consumers to radical fuel price spikes arising from the reality of supply chains. Converting a grid's fuel supply for conventional generation from long-term baseload contracts to episodically buying huge quantities, not only exposes consumers to huge price spikes, it creates those spikes.

The other option increasingly discussed, and even mandated in some states, is the use of grid-scale batteries. It's relevant to note that using solar and wind as a primary source of electricity—which some propose—means that grids will requires at least *twice* today's installed generating capacity. Far more than the normal peak generation would be needed to supply *both* peak demand when sunlight and wind are available, *and* to have surplus to simultaneous store in batteries. Such costs are typically not included in the calculus of aspirations for greater use of solar/wind on grids.

One can estimate the quantity of batteries required to, say, provide an average of 12 hours of backup for the nation. That's a quantity some analysts propose would be sufficient to allow an all solar/wind grid to keep America's lights on 99.97% of the time. That sounds good except that, statistically, mean on average, there'd be a few hours of zero power every year, or as a practical matter, nearly a half-day of no power, anywhere, every few years or so.

Nonetheless the nation is on track to build far more grid-scale batteries. And to be clear, those will be very useful for many short-term outages and other grid management and stability issues. But when it comes to using batteries to fill the solar/wind droughts that are inevitable, the 12-hour storage target for the nation would require spending over $1 trillion to build enough batteries. Even then, as the meteorological record shows, there will be frequent episodes in the foreseeable future when the entire nation would be lights-out if there isn't enough conventional generation available. For comparison, about $100 billion in capital—one tenth as much as the battery solution—is associated with the "excess" capacity on today's grid to ensure the lights are always on.

As for claims that batteries will soon become far cheaper; last year saw a dramatic slowdown in the decadal trend of battery price declines. Average lithium battery prices were down just 6% in 2021 and are forecast to *rise* this year. The reason is found in the fact that mineral commodities account for 60 to 70% of the cost to build a battery. Going forward, mineral commodity inflation will be fueled by the unprecedented increases in mineral demands to build energy systems.

The International Energy Agency, amongst others, has documented the magnitude of minerals that will be needed to accommodate massive increases in battery production for grids and, simultaneously, for electric cars. Combined with aspirations for greater use of solar and wind technologies—which also require far more minerals than conventional generation—the IEA estimates the world needs a 400% to 4,000% increase in mining of a range of critical energy minerals in the coming decade or two. Such an unprecedented increase in global mining is not now underway, nor planned—nor I might add, particularly encouraged by most policies.

Such surprising materials demand comes from physics realities. Batteries are an extremely challenging and expensive way to store large quantities of energy. It requires about 50 tons of batteries to hold the amount of energy contained in one ton of oil. And storing a ton of the later is very easy and cheap. Obtaining the minerals needed to fabricate the 50 tons of batteries requires mining and processing roughly 25 thousand tons of materials. This kind of disparity really adds up at grid scales.

Building enough grid-scale batteries for 12 hours of storage for the U.S. grid—never mind other grids in the world—would entail mining a quantity of materials equal to that needed to fabricate

100 centuries worth of batteries for all the world's billions of smartphones. This calculation doesn't count the minerals needed for the expanded use of electric cars, or the "energy minerals" needed to build the wind and solar machines.

Of course, it's reasonable to expect that different and even superior chemical concoctions will be discovered for future batteries. But it takes many years, even decades to make progress from discovery to industrial scales. For the usefully foreseeable future, and certainly in the timeframes contemplated in many policies, the technologies that exist today are what will be used to build systems.

It bears noting the geopolitical implications of all these energy minerals. China is not only the primary supplier of the world's polysilicon for solar modules, but it is also the single largest source—by most accounts nearly half—of most of the critical materials needed to build batteries. The United States is a minor player. The rush to build battery assembly plants here in America is the equivalent of building cars here but importing all the gasoline.

Finally, building batteries, solar and wind machines at grid-scale is not fundamentally different than building anything else at such scales. All of it always entails massive uses of materials, construction equipment, time, capital and, critically, regulatory clearances and permits.

Building and installing enough hardware to replace all of America's conventional gas- and coal-fueled electric power plants by, say, 2040 would require a *continuous* grid construction program several hundred percent greater than occurred during any single peak year of grid construction over the past half-century. Such an endeavor would be, quite literally, an industrial effort comparable to a World War II level of mobilization. And it wouldn't be possible without clearing away regulatory delays, something that is not now being proposed anywhere.

Our increasingly digital economy, which everyone recognizes is ever more important to fueling economic growth, will require both more electricity and especially more reliability. While there is clearly a role on modern grids, and one greater than today, for solar, wind and battery systems, caution is in order when it comes ensuring the reliability of society's most critical infrastructure.

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