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Do Coal and Nuclear Generation Deserve Above-Market Prices?

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Abstract

All 14 current rationales for mandating or subsidizing uncompetitive coal and nuclear plants lack technical merit or would favor competitors instead. Subsidizing distressed nuclear plants typically saves less carbon than closing them and reinvesting their saved operating cost into severalfold-cheaper efficiency. Carbon prices, not plant subsidies, best recognize decarbonizing attributes. Grid reliability needs careful integration of diverse, distributed demand-side and renewable resources, using competitive market processes and resilient architectures, but does not require "baseload" plants.

Keywords

Coal, nuclear, carbon, competition, efficiency, renewables

Author biography

Physicist Amory Lovins has advised major firms (including utilities) and governments worldwide for over 40 years; written 31 books and over 600 papers; and received the Blue Planet, Volvo, Zayed, Onassis, Nissan, Shingo, and Mitchell Prizes, MacArthur and Ashoka Fellowships, 12 honorary doctorates, the Heinz, Lindbergh, Right Livelihood, National Design, and World Technology Awards, and Germany's Officer's Cross of the Order of Merit. An honorary architect, Swedish engineering academician, and former Oxford don, he has taught at ten universities. *Time* named him one of the world's 100 most influential people, and *Foreign Policy*, one of the 100 top global thinkers.

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Do Coal and Nuclear Generation Deserve Above-Market Prices?

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The new federal Administration faces an unusual dilemma in forming a coherent electricity strategy. Its Secretary of Energy[1] has said that coal and nuclear power plants too costly to clear in competitive markets must be kept running anyhow for "national security," even if doing so requires overruling state regulation and (by implication) ISO/RTO practices.[2] The Secretary ordered a quick staff study to seek an analytic basis for his policy, but finding credible support won't be easy. Without clear statutory authority to execute his policy, his evidence—and the transparency, objectivity, and stakeholder participation of his study's process—would need to persuade judges to set aside the conclusive, consistent, and empirically validated findings of virtually all prior expert studies by his own Department[3] and its National Laboratories,[4] the grid reliability regulator[5], grid operators like PJM[6], MISO[7], WECC[8], SPP[9], ERCOT[10], and CAISO[11,12], trade associations[13], the International Energy Agency[14], many foreign and academic experts, and leading global electricity-industry firms.

This evidentiary challenge is compounded by the policy's internal contradictions. Efficient end-use is steadily shrinking the electricity sales for which all generators compete,[15] and that shrinkage will intensify.[16] Coal and nuclear plants have both done poorly in capacity auctions meant to favor them[17], losing mainly to gas and casting doubt on their reliability claims. Coal and nuclear are also uneasy yokemates: they compete toe-to-toe. Illinois's new long-term nuclear subsidy drove down regional capacity prices 98% in a year, making Dynegy move to close most or all of its Illinois coal capacity.[18] Its Vice President Rob Hardman called[19] nuclear operating subsidies the "new front in the War on Coal," while his colleague David Onufer said state-by-state policies "have turned markets from a competition to produce the lowest cost electricity to a competition for [nuclear] subsidies."[20] Claiming, as EPA Administrator Pruitt did[21], that coal plants' avoidance of vulnerabilities in the natural-gas pipeline network confers a national-security advantage also undermines the case for fracking—the main actual market threat to coal and nuclear plants[22], but another strong Administration favorite.

Pricing CO_2 emissions as Republican elder statesmen urge[23] would hurt both coal and gas, help nuclear against gas, but not help nuclear beat renewables, which increasingly beat coal, gas, and nuclear wherever allowed to compete. Renewables also enjoy strong bipartisan political support; California rooftop solar adoption was found to be five times greater in Republican- than in Democratic-leaning areas[24], over four-fifths of U.S. windfarms are in Republican congressional districts, and the top six windpowered states all voted for Donald Trump. Red-state sentiment is bolstered by outstanding commercial successes like Texas windpower, whose 25,000 jobs, 15% of electricity, and record-low 2016 wholesale electricity prices culminated under Energy Secretary Perry's leadership as Governor. In Iowa, the first state to become more than one-third windpowered (now 37%), Senator Grassley said[25] the tax credits he authored could be attacked "over my dead body," and trenchantly added[26] that many in favor of "all of the above" energy policies are "really for none of the above and all of the below"—i.e., not for renewables but for dug-up fuels.

Across the country and across party lines, state regulators and states'-rights advocates will fiercely guard their prerogatives. ISO/RTOs will defend the competitive markets that Congress and many states told them to build to provide adequate and reliable electricity at the lowest efficient price. Customers and merchant generators will fight for those markets' benefits. Financiers will shun added risks. The military will continue to lead renewable deployment for its own operational success and mission continuity: it was then-General Mattis who famously appealed from Iraq in 2003 to "unleash us from the tether of fuel."[27] Over three million renewable workers—California has more solar workers than America has coal-miners—will defend their jobs. And judges will restrict the executive to reasoned administrative decisions and legally authorized powers.

Amidst the debate trigged by Secretary Perry's statements, the Federal Energy Regulatory Commission convened a lively 1–2 May 2017 Technical Conference to examine whether the Eastern Interconnect's wholesale energy and capacity markets are properly pricing electrical resources to ensure reliable, resilient, and affordable electricity supply, and how state actions to advantage specific resources may affect those technology-neutral markets. This article adapts, expands, and updates my written comments[28] to FERC for that event.

Around-market nuclear subsidies' climate protection rationale

FERC's focus on some state policymakers' efforts to select or advantage specific resources that can't compete in technology-neutral wholesale markets arose mainly from new long-term state subsidies to specific distressed nuclear plants, as recently adopted by Illinois legislators and New York regulators, and together totaling perhaps $10 billion. There is no competition to obtain the targeted payments, and renewables can't get them. Those bailouts are being litigated[29,30] amidst uncertainties in Federal law.[31] Similar bailouts are being considered in Connecticut, New Jersey, Ohio[32], and Pennsylvania. A Bloomberg study estimated customer costs up to $3.9 billion a year if the 28 GW of Northeast and mid-Atlantic nuclear plants won New York-level subsidies, so the losers would be customers and competitors. Such subsidies are influenced by local political considerations like jobs and tax revenues, and are sometimes extorted from states under threat of abrupt nuclear shutdowns that would disrupt grid operations. But their main rationale is the climate benefit of prolonging a carbon-free (in operation) resource for as long as safely possible.

I believe this argument is fundamentally mistaken and the claimed climate benefits are illusory, because of climate opportunity cost: avoiding and properly reinvesting nuclear operating cost (opex) can save even more carbon. Using 2013 $ throughout, the argument is:

1. Distressed nuclear plants' high opex makes them uncompetitive in wholesale markets. Estimates of the number of such plants vary widely but seem to trend upward, because their economic challenges are rising, and so are proposals for subsidies that would reward exaggerating those challenges.
2. Individual nuclear plants' and units' opex (and financial performance) are generally secret, but aggregated data from the Electric Utility Cost Group, published by the Nuclear Energy Institute, show that the latest available nuclear opex, for 2010–12, averaged 6.2¢ per busbar kWh for the highest-cost quartile and ~4¢ for the third-highest-cost quartile.[33] Opex for the average 2014–15 nuclear plant was ~3.5¢/kWh[34], exceeding many modern renewable bids.

3. Closing a distressed nuclear plant would avoid its opex, with immaterial effect on present-valued decommissioning cost (which must be paid anyway somewhat later).
4. Utilities pay an average of 2–3¢/kWh to buy end-use efficiency for customers.[35]
5. Closing an average top-opex-quartile nuclear plant *and* buying equivalent efficiency instead, as state regulators could require, would therefore procure (at the average price) 2–3 kWh of efficiency for each nuclear kWh not generated. One of those kWh could serve the nuclear output's function while the other 1–2 kWh could displace fossil-fueled generation.
6. This swap of nuclear operations for a greater quantity of efficiency could save at least as much carbon, plausibly twice as much, as if a fossil-fueled plant had been closed instead.
7. This ability to close a nuclear plant *and* cut CO_2 underlies PG&E's multi-stakeholder agreement to close the Diablo Canyon two-unit nuclear plant—well-running but redundant and with a forward levelized operating cost ~7¢/kWh—and buy cheaper efficiency, renewables, or other carbon-free resources instead.[36] The mix will be determined by California's Integrated Resource Planning process so that market competition can find the cheapest carbon abatements, subject to reliability and other constraints. PG&E agreed that this orderly substitution for Diablo Canyon—cheaper to close than to run (by ≥$1 billion NPV, says NRDC)—will make the grid more flexible, emit no more carbon, and deliver other societal benefits. Allowing enough time for graceful carbon-free substitutions will avoid the interim rise in gas-fired generation ascribed to past abrupt nuclear shutdowns like San Onofre. (Vermont Yankee is often so cited too based on first-year data, but ISO-NE's 2014–16 nuclear output loss was 91% offset by renewables and hydro-dominated imports, and another 69% by reduced sales.[37])
8. Thus the argument that reducing CO_2 emissions requires new subsidies for uncompetitive-to-run nuclear plants is generally wrong. (Even for lower-opex plants, around <2–4¢/kWh, it may not be true if cheaper-than-average efficiency is substituted.)
9. These comparisons are conservative because efficiency is already delivered to the retail meter, so it defers or avoids any marginal components (operating costs and losses, modernization, upgrades, expansions) of the embedded average ~4.1¢/kWh cost[38] of delivery.

In summary, closing a nuclear unit in at least the top quartile of operating costs (>6¢/kWh) does not directly save CO_2, but can indirectly save *more* CO_2 than closing a coal-fired power plant *if the nuclear plant's larger saved operating costs are reinvested in efficiency* that in turn displaces more fossil output. Exact values will depend on specific details, but the logic is unavoidable if one tracks both carbon *and* money. New York and Illinois policymakers apparently thought only about carbon, not also about avoidable opex and how its reinvestment could save more carbon.

Broadly, such reinvestment enables closing either an average coal plant *or* a high-operating-cost nuclear plant to avoid similar releases of fossil carbon—and the latter plausibly even twice as large. Thus neither kind of closure should be discouraged. But buying a carbon abatement that does not save the most carbon per dollar results in emitting more carbon than necessary. Nuclear *new*-build is clearly many times costlier than almost any alternative[39], so it makes climate change worse than if the best buys, saving far more carbon per dollar, were procured instead.

Additional nuclear subsidies are claimed to be justified by market failure. On the contrary, they create it. Around-market subsidies like those just adopted in New York and Illinois distort pool-wide prices, crowd out competitors, discourage new entrants, destroy competitive price discovery, reduce transparency, reward undue influence, introduce bias, pick winners, and invite corruption. As the former chairs of the New York and Texas Commissions—one a former Nuclear Regulatory Commissioner and NARUC President, the other a recent FERC Chairman—agreed,[40] such targeted subsidies may "unravel U.S. power markets altogether." Before approving such radical arrangements, FERC, ISO/RTOs, the states, and the courts should require a high standard of proof that the market is unable to provide a cost-effective solution to a real problem, for reasons that cannot be fixed within market principles. The burden of proof should be on proponents of around-market subsidies. Absent definitive proof, the market should be allowed to work.

States have many tools for valuing specific attributes like carbon-free operations. For example, states wanting to buy carbon-free resources without harming existing market mechanisms could run a laddered series of auctions open to all such demand- and supply-side options. This free-market approach would value the carbon-free attribute without substituting policymakers' prophecies for evolving prices discovered in the market.[41] Historically, such guesses have almost always been wrong, and that risk is rising because prices are in rapid flux. During 2008–16, a period shorter than the duration of the New York and Illinois nuclear subsidies just added, average U.S. real PPA prices fell 83% for PV power and 71% for windpower.[42] In 2016 alone, global prices fell by 17% for solar PV, 18% for onshore windpower, and ≥16% for lithium-battery storage, and their fall is accelerating. Regional prices can be even more volatile, falling in about eight months of 2016 by 37% for Mexican solar PV and 43% for European offshore windpower. In this maelstrom, no policymaker, however wise, can be confident of guessing 2027–29 relative prices. It's foolish to substitute long guesses for market outcomes constantly calibrated to reality. Illinois' new nuclear subsidies, rejecting such competition, were rationalized on the grounds that renewables could not compete without the deal-sweetening RPS increase, but some local renewable developers dispute that and deny they were given a fair chance to disprove it in the market.

Continued nuclear operations might win such a carbon-abatement auction initially, until cheaper new efficiency and renewables ramped up and won on cost per unit of time-integrated carbon avoided; but markets, not regulators or legislators, should determine that outcome. Nuclear operators' insistence on locking in decade-plus subsidies is especially harmful to market flexibility, innovation, and competition. It rejects and defeats the whole purpose of having wholesale power markets. In my view, operators that insisted on restructuring so they could benefit from wholesale markets should live with the consequences. After all, they've been compensated first for building their assets (with subsidies around 0.8–4.6¢/kWh for shareholder-owned and 1.7–6.3¢/kWh for public utilities, excluding ~8.3¢/kWh of historic subsidies that originally launched the nuclear enterprise[43]), then for transition costs of the restructuring they later demanded (notably "stranded-asset" allowances), sometimes yet again by some ISO/RTOs' additional capacity payments favoring large thermal units, and now (they hope) for a fourth time via new state payments and competitive boosts for alleged unrecognized virtues. Once is enough.

Carbon and other pollution pricing

Coal and nuclear power plants have a growing number of real or imagined attributes for which their owners would like to be paid more so they can keep milking those amortized assets despite ever more competitive markets. The suite of properties said to merit added payments, whether via higher wholesale prices or other subventions, keeps expanding, and currently comprises at least the 14 elements analyzed here. The first of those, the claimed climate benefits just discussed, is often expressed in a different form: that U.S. reactors aren't rewarded at a national level for not directly emitting CO_2, conferring unfair advantage on fossil-fueled plants that do. (The Regional Greenouse Gas Initiative,[44] however, is designed to cap, trade, and cut power-sector CO_2 emissions in nine states—including New York, which just added nuclear subsidies for the same purpose, and Connecticut, which is being asked to.)

I agree with the Nuclear Energy Institute that pricing CO_2 emissions—and for that matter other air pollutants, as California has done for NO_x since 1994—is desirable and would help nuclear plants compete with gas-fired plants. However, it would equally advantage carbon-free renewables—a cheaper, nonvolatile-and-declining-price, more resilient, more popular, and more potent and ubiquitous competitor than gas. If avoided carbon or other emissions are valued, they should be valued equally for all resources, and in principle should recognize all material externalities.[45]

Rather than acknowledging that carbon pricing wouldn't help nuclear power beat renewables—and should replace, not augment, nuclear subsidies—nuclear advocates argue that (a) renewable energy has an inherently limited role, especially in providing reliable supply, while (b) nuclear power has *other* important attributes not recognized in its wholesale-market power price. These are claimed to cause "market failures" and "inefficient pricing" that regulators or ISO/RTOs should change market structure to correct. We turn next to those attributes.

Subsidies

Secretary Perry's view that "federal subsidies that boost one form of energy at the expense of others" can distort markets and may weaken the grid is a compelling objection to New York's and Illinois's new nuclear subsidies. However, even as such state policies' contagion spreads, their logical basis is collapsing, for two reasons. First, as noted above, their climate (or other environmental) rationale is mistaken. Second, the subsidies relevant to current power-market prices, some current and others long in force but still affecting today's prices, appear to be generally larger and more durable for fossil-fueled and nuclear plants than for modern renewables.[46,47] As a small example, new U.S. nuclear plants get slightly higher operating subsidies per kWh than new U.S. windfarms[48], plus far larger capital subsidies, around 5–12¢/kWh, rivaling their construction cost—and even existing nuclear plants' capital subsidies often exceed the wholesale price they receive.[49]

The whole energy system is riddled with opaque subsidies—federal, state[50], and local. I earnestly hope the Secretary will seek a comprehensive and unbiased assessment of *all* energy subsidies (unlike slanted EIA studies that Congressional sponsors carefully structured to produce biased conclusions[51]). The last thorough federal-subsidy assessment I know of, for FY1984[52], found 1–2-order-of-magnitude distortions favoring incumbents. Bringing such work up to date, as Doug Koplow has valiantly attempted without official help,[53] would be a vital tool for crafting fair policies to desubsidize the entire energy sector.[54] Honest analysis of *all* energy subsidies, current (which PJM and FERC consider) *and* relevantly previous, for both capital and operating costs, will probably find that nuclear and coal electricity are already more heavily subsidized than solar and windpower. If so, then leveling the playing field, as the Secretary and I both advocate, would not help but harm the coal and nuclear resources he aims to advance; but I'm glad we agree on the principle even before we know the up-to-date numbers.[55]

History, though, suggests energy subsidies are a triumph of political muscle over principle. That's why the 1986 Tax Reform Act cut the hydrocarbon industries' taxes *and* kept their specific tax subsidies. But unbalanced energy subsidies are rising. Broadly speaking, all renewable subsidies are declining, fossil-fuel subsidies aren't, and already-large nuclear subsidies are rising sharply. The Secretary seems inclined to intensify the resulting market distortions. As someone who takes market economics seriously (though not literally), I think that's a bad idea and rejects conservative free-market principles.

"Large-scale" electricity generation

A traditional giant power stations produces far more power than practically any application needs except uranium enrichment plants and giant metal-smelters. A gigawatt exceeds the typical electricity draw of a typical office building by several orders of magnitude, of a home by about five, of a home air conditioner by five or six, and of a laptop computer by about eight. Those power stations are built so big simply because their construction cost per kilowatt becomes even more prohibitive if they're smaller. Economies of unit scale in construction are real, and can apply also to solar and wind facilities that are typically one to three orders of magnitude smaller. However, more than 200 *dis*economies of scale are even more important to the *customer's* economics. Better matching scale of supply to scale of use generally reduces total cost and risk.[56]

Every kind of electricity generator sometimes breaks, but some fail more gracefully than others. Big, lumpy units make failure (in generation or its transmission pathways) more consequential, requiring larger reserve margin, spinning reserve, and cycling costs than with a diversified and distributed portfolio of small, granular units. The latter also improves resilience, as we'll see.

"Baseload" generation

Secretary Perry asserts[57] that "baseload" plants are "critical" resources "necessary to a well-functioning electric grid," so national security may require their continued operation and hence preemption of state policies exposing them to full and fair competition. This traditional view reflects a common misperception about what "baseload" means; the word has at least five meanings.[58] It simply encapsulates how an inflexible big thermal generator functions and the role such plants have historically played on the grid. It is not a grid need today. This has been clearly stated by, among others, former FERC Chairman Jon Wellinghoff[59], National Grid CEO Steve Holliday[**60**], and GE (which says[61] inverters can provide frequency response and other ancillary services even better than synchronous generators). Indeed, inflexible baseload generators are becoming an impediment to further grid integration.[62] The weight of expert opinion clearly concurs.[63,64,65,66,67] As Bloomberg New Energy Finance's founder wrote,[68]

> Super-low-cost renewable power—what we are now calling "base-cost renewables"—is going to force a revolution in the way power grids are designed, and the way they are regulated.
> The old rules were all about locking in cheap base-load power, generally from coal or hydro plants, then supplementing it with more expensive capacity, generally gas, to meet the peaks. The new way of doing things will be about locking in as much locally-available base-cost renewable power as possible, and then supplementing it with

more expensive flexible capacity from demand response, storage and gas, and then importing the remaining needs from neighbouring grids.

New nuclear plants will remain the political bauble they currently are, unless next-generation nuclear can prove it can deliver fail-safe designs at affordable cost. Demand will be suppressed by energy efficiency and self-generation, and augmented by electrified transport and heat.

Putting super-cheap, "base-cost" renewable power at the heart of the world's grids in this way will require a revolution in the way the electricity system is regulated. Renewable power's progress to date has been achieved mainly by subsidizing or mandating its installation, while forcing the rest of the system to provide flexibility, within otherwise unchanged regulatory environments and power market rules. The additional system costs have been material but generally affordable….[But we] are reaching the point…where power system regulation will have to be fundamentally rethought. Simply layering on a capacity market is the wrong response: creating guaranteed demand for obsolete technologies has never ended well.

Confirming the feasibility of reliable, largely renewable supply without a "storage miracle," four EU countries with modest or no hydropower met 46–64% of their 2014 electricity needs with renewables (Spain 46%, Scotland 50%, Denmark 59%, Portugal 64%), with no added bulk storage yet superior reliability. In 2015, the ultrareliable former East German utility 50Hertz was 49% powered by renewables, three-fourths of which were wind and PV—~9× what was thought possible 10–15 years ago, says its CEO—yet its last high-voltage outage was many decades ago, and he says 60–70% variable renewables would not require more bulk storage.[69] What has changed, he explains, is the evolution of mindset and of adaptive market mechanisms. The modern view is that supposed storage and backup needs are less a need of variable renewables than a consequence of central thermal plants' relative *in*flexibility. That's not the renewables' fault.

Dispatchability

ISO/RTO bidders must satisfy uniform, pool-wide reliability criteria. Sustaining those standards as variable renewable fractions increase requires careful, non-trivial, but well-proven and well-understood technical and institutional improvements.[70] These tend to become more burdensome if inflexible and uncompetitive resources are retained. Grid balancing costs may be paid by the system or by new resources. Most current U.S. practice does this asymmetrically, favoring incumbents over new entrants. Specifically, variable renewables' grid balancing costs are generally borne by their developers or owners, and are usually <$5/MWh, nearly always <$10.[71] Yet coal and nuclear plants impose analogous costs on the system without being charged for them, at least outside ERCOT. Instead, the grid balancing costs of managing the intermittence (forced outages) of central thermal plants—reserve margin, spinning reserve, cycling costs, part-load penalties—are traditionally socialized, treated as "inevitable system costs," and hardly ever analyzed.

This asymmetry appears to favor fossil-fueled and nuclear plants, because their balancing costs, emerging evidence suggests, may be severalfold *greater* than those of a well-designed and -run portfolio of PV and wind resources. Conversely, variable renewables may need *less* backup (or storage) than utilities *have already bought* to manage the intermittence of their big thermal plants. (For example: utilities have found that high wind fractions can be firmed by fueled generators ≤5% of wind capacity—severalfold below classical ~15–20% reserve margins for thermal-dominated systems.[72] Unbundled ERCOT ancillary-services market price data confirm that wind's reserve costs per MWh are about half those of thermal generation.[73,74] NREL's models confirm for the western U.S. that central thermal plants cost more to integrate than variable renewables.[75]) FERC should investigate these grid balancing costs, and ensure they are analyzed and applied symmetrically for *all* resources—big and small, renewable and nonrenewable, supply- and demand-side—or are treated as system costs not charged to a specific resource type.

Loadshape value

ISO/RTOs should and do consider match to load, and most compete load flexibility resources against supply. PVs' often-strong correlation with midday peak loads can be valuable, but big thermal plants' relatively steady output (in between outages) is of no special value to modern grids, which require energy, capacity, flexibility, and ancillary services rather than steady generation. The faster ramp rates required to integrate high fractions of variable renewables can be gracefully managed without bulk storage, and not only by the latest fast-ramping gas plants, because many other resources are also flexible but cheaper. For example, preliminary research at RMI recently found that demand response could more than eliminate California's "duck curve" and halve daily load variation with a roughly 5-month payback. Other important grid-balancing resources include efficient end-use, precise forecasting of variable renewables, their diversification by size and location, their integration with dispatchable renewables and with cogeneration, thermal storage, hydrogen storage, and distributed electricity storage including electric vehicles.

"Fuel on hand"

"Fuel on hand" is a new label for coal and probably for nuclear plants—what's left after excluding gas-fired generators (whose fuel is delivered just-in-time by pipelines) and renewables (which burn no fuel). EPA Administrator Pruitt refers specifically to "solid hydrocarbon fuels on hand"—meaning coal, not also uranium—but apparently with Secretary Perry, let's assume both.

The notion that "fuel on hand" enhances grid resilience by reducing dependence on fuel logistics seems intuitively plausible. But an initial review[76] of historic experience suggests it's incorrect even in its own narrow terms (fuel logistics is an important but far from exclusive or dominant part of the spectrum of threats to electric resilience). Renewables need no fuel but aren't mentioned in the Secretary's memo. Moreover, coal and gas delivery exhibit worrisome weaknesses that concern NERC, the grid-reliability regulator. Coal plants have proven vulnerable to fuel-logistics problems—rail and bridge failures, frozen barges and onsite coal piles, etc. Gas infrastructure suffers freezeups and the inherent physical[77] and cybervulnerabilities of pipeline systems. Nuclear plants have suffered mass shutdowns caused by accidents, safety concerns, heat waves, and grid failures, and some failures can persist. For example, in the 14 August 2003 Northeast blackout, nine U.S. nuclear plants SCRAMmed from 100% to 0% output as designed, but then took nearly two weeks to restore (<3% in three days, 41% in seven days), due largely to xenon and samarium poisoning and core-flux inhomogeneities.[78] This inherent physics attribute makes power reactors an "anti-peaker" resource, guaranteed unavailable when most needed.

Photovoltaics and windpower are variable, with average respective 2016 U.S. utility-scale capacity factors of 27.2% and (net of several points' curtailment) 34.7%.[79] Yet their variations are generally more predictable than are variations of electricity demand. PV and windpower also have far lower forced outage rates than big thermal stations, typically <1% and 1–2% respectively (for a leading brand of utility-scale PV inverter, nearly the only failure source in such projects, the guaranteed maximum is 0.15%). These renewables have repeatedly sustained reliable grid service when fueled stations' failures endangered it. Other kinds of renewables are dispatchable and also have very high technical availability.

Just comparing different generating plants misses the most important point: distributed resources can largely or wholly bypass *grid* failures, which trigger ~98–99% of U.S. power outages.[80] Distributed generators can thus be especially resilient, especially if architected as islandable microgrids that normally exchange power freely with the larger grid but can isolate and stand alone at need, serving at least the critical loads from local resources until grid service is restored. That's how my house works. It's how the Department of Defense aims to power military bases, because they need their stuff to work. So do the rest of us citizens whom they're defending. Liberalized policies for distributed renewables, like the plug-and-play rule pioneered in Texas by PUCT Chair Pat Wood under Governor George W. Bush, should make resilient hookups (which protect lineworkers by standards like IEEE1547) the legal and normal default design, so America's renewable adoption can build a resilient grid from the bottom up.

Price deflation

The supposed inevitability of renewables' "eating their own lunch"—because high renewable fractions depress wholesale prices, making it progressively harder to elicit further investment—is an artifact of models that artificially constrain or exclude ways to mitigate this problem (if lower prices are a problem rather than a societal benefit).[81] Though featured in a major MIT study[82], such "price deflation" has not withstood analysis—and identical modeling of nonrenewables, especially nuclear power, would show "price deflation" affects them worse than renewables..

Such issues are described differently from different perspectives. For example, renewables' and gas-fired electricity's reductions in wholesale prices are called "price suppression"[83] by the nuclear industry when they beat its plants in "merchant markets," wrongly implying that the price verdict is somehow wrong and needs fixing. Carbon should indeed be priced as discussed above, but other nuclear attributes do not appear to merit higher payments for real value delivered.

Accounting vs. *economics*

The prior employer of the head of Secretary Perry's new grid study claimed[84] (along with exorbitant supposed storage needs) that revenues lost by incumbent thermal plants are an "imposed cost" of the renewables that outcompeted them. This novel theory would have had Netflix compensate cable-TV providers and Henry Ford compensate horse-stable owners. Such a proposed barrier to competition and innovation confuses economics (sunk costs) with accountancy (unamortized assets). Under the rubric of "utilization effect," it was soundly rejected by two EU workshops advised by the theory's originator. Those workshops found that society bears transformation costs and needn't ascribe them to particular technologies, new or old, nor to particular parts of the power system.[85] Of course, renewables with virtually zero dispatch cost do push higher-opex thermal plants up the load-duration curve so they run less. Customers then benefit from lower market-clearing prices. Owners suffer from correspondingly lower revenues for which they would love to be made whole. But they were already compensated for all the risks of their investments, including competition and innovation, and should not be paid twice.

Financial economics of volatile fuel prices

A major distortion in wholesale power markets is their typical failure to risk-adjust different resources. To compare volatile-price resources, notably gas-fired power plants, fairly against fixed-price resources, like efficiency and renewables, requires risk-equalization by adding to volatile cost streams the market value of their price volatility (which can be approximated by the straddle in the options market—the spread between the prices of simultaneous put and call options). For natural gas, that volatility value approximates recent natural-gas prices, so plant and grid operators that don't count the gas-price risk are imposing on customers all the burdens of acting as if gas cost only about half as much as it actually does on a risk-adjusted basis. A sophisticated recent analysis using a different method found that properly counting gas-price volatility makes modern renewables robustly cheaper than efficient combined-cycle gas plants.[86] Coal has also recently exhibited considerable price volatility meriting analysis and risk-adjustment.

FERC and ISO/RTOs that don't risk-equalize for the volatile prices of gas and other fuels are creating a market failure. Nearly all market players routinely do the same. That violation of the basic principles of financial economics should not become customers' problem. The next time someone says, as the chairman of a large utility told a *Wall Street Journal* conference a few years ago, "Windpower can't compete in my area because I have two-cent[-opex] gas power," please reply: "Just a minute. You're being offered windpower at a fixed nominal price, hence a declining real price, for at least 20 years. How much two-cent gas power do you want to sell me on those terms?" The answer, of course, was zero—the gas was a spot price—but then the conversation about "cheap gas" continued as if nothing had happened. Policymakers should know better.

Local expenditures and jobs

Big thermal plants employ people and pay taxes. State and local governments will properly consider this, but such production costs are hardly a basis for raising the prices ISO/RTOs pay for the resource. All reasonable costs of generation are costs, not benefits; are reimbursed by ratepayers; and should not be paid again via added subsidies. At least for employment, such local benefits are also empirically inferior to those of equivalent efficiency and renewables.[87]

Nuclear power's support for the U.S. nuclear weapons program

Secretary Perry's novel assertion[88] that maintaining civilian nuclear power because its technical expertise and manufacturing capabilities are vital to the U.S. nuclear weapons capability (partly via links that cannot be discussed because they're highly classified) will doubtless be rebutted by nuclear weapons experts. It could also embarrass the nuclear industry, whose brand is built on the longstanding (if dubious[89],[90]) claim that nuclear power and nuclear weapons are wholly unrelated. In the United States, actual civilian/military nuclear links are too tenuous to violate the Non-Proliferation Treaty's obligation to use nuclear energy for *exclusively* peaceful purposes; unlike several other major nuclear-weapons states (such as France and UK) where the two sectors are intimately linked, U.S. materials-production links are minor and readily transferable to existing military facilities. But the Secretary's suggestion that uneconomic civilian nuclear energy must be sustained because its intellectual and manufacturing support of the nuclear weapons establishment is vital to national security will astonish all three of those expert communities. And if the claimed linkages were real, defense budgets, not electric bills, should pay for them.

Diversifying power supplies

As U.S. electricity supply rapidly diversifies away from incumbents' coal and nuclear assets and toward insurgents' gas and renewable assets plus efficient and timely use, the supply portfolio is getting more diverse, not less. Incumbents naturally want their own legacy assets retained on grounds of still greater diversity. However, "The commendable impulse to diversify power sources does not require substituting one particularly brittle and costly source for another, any more than diversifying a financial portfolio will make it perform better if you unwisely choose costly and risky investments."[91] It's therefore fortunate that efficient market outcomes—choosing demand-side and renewable resources over gas-fired generation, and all of these over coal and nuclear generation—can also enhance reliability, resilience, choice, competition, national and community security, climate protection, and Creation care.

Fourteen magical properties claimed for coal and nuclear power stations

The electricity debate sparked by the 2017 change of federal Administration is just beginning. Perhaps my taxonomy of 14 novel virtues claimed for prolonging the operation of coal and nuclear plants (if not building more), and arguments that customers should pay more and competitive markets should give way to obtain those virtues, will help inform a discussion that needs clear thinking, rigorous logic, and sound evidence. So far, the proposed case for compensating coal and nuclear plants more than wholesale power markets now do is not convincing. This article, reinforced by other recent analyses,[92,93,94,95], has explained and documented why:

1. Prolonging the operation of distressed nuclear plants reduces and retards climate protection, because high operating costs avoided by retirement could buy more carbon savings.
2. Pricing carbon and other pollutants, instead of adding targeted subsidies, would properly recognize zero-emission resources, advantage nuclear against gas and coal, and not distort nuclear power's competition with renewables. (Broader internalization to reflect other attributes may not favor nuclear power.) In contrast, targeted nuclear subsidies harm power markets vital to competitive renewable deployment, block new entrants, and stifle innovation; they protect the old energy system rather than enabling the new one.
3. Thorough and independent analysis of subsidy streams would probably find that nuclear and fossil-fueled generation are more subsidized than renewables.
4. "Large-scale" generation is not needed, and decreases net economic value and resilience.
5. "Baseload" (large, thermal, relatively steady) generation is not a needed attribute, but often brings inflexibility that complicates grid management and inhibits renewable uptake.
6. The rich menu of grid flexibility resources, of which bulk storage is the costliest and least necessary, makes dispatchability no longer a vital attribute. Maintaining reliability despite high fractions of variable renewables requires well-known improvements to operations, grids, and markets. Renewables are generally charged for these, but big thermal plants are not charged for their corresponding balancing costs, which emerging evidence suggests are probably larger.

7. Coal and nuclear plants merit no special rewards for their relatively steady output shape—quite the contrary, as their inflexibility complicates grid integration.
8. Coal and nuclear plants' "fuel on hand" has not historically shielded them from widespread coincident failures arising onsite or in upstream infrastructure, and hence does not improve grid resilience. Rather, their large unit scale reduces resilience and increases backup costs.
9. Resisting "value deflation" is a greater problem for nonrenewable than for renewable generators, and for renewables, has been greatly exaggerated by modeling artifacts.
10. Charging renewables for "imposing" coal and nuclear plants' competitive losses is improper and contrary to accepted market principles whereby competitors win or lose.
11. Financial economics requires, but many buyers neglect, counting the market value of fuels' price volatility. Doing so would recognize renewables' and efficiency's valuable fixed-price attribute and reduce societal risk.
12. Coal and nuclear plants' outlays for payrolls and taxes are reimbursed by customers, are costs rather than benefits, should not be specially rewarded in power markets, and support fewer jobs per MWh than do equivalent efficiency and modern renewables.
13. Nuclear power's claimed support for U.S. nuclear weapons programs seems illusory (and contradicts the industry's branding), but it were real, should be paid for via defense budgets, not electric bills.
14. Modern renewables and demand-side resources are rapidly diversifying U.S. electricity from vulnerability toward resilience. Retaining obsolete and less resilient technologies for the sake of diversification would advance this goal in name but not in practical effect.

These conclusions suggest that if the lively and worthwhile national debate Secretary Perry has launched is well-informed and transparent, its conclusions should support wider use and faster deployment not of coal and nuclear energy but of efficiency, flexible loads, and modern renewables. Elucidating the complex and important issues the Secretary has raised should build understanding, advance the national interest, and enhance global prosperity and security. Experts who understand these issues have a special responsibility for promptly contributing to the debate.

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