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The coming transformation of the electricity sector: A conversation with Amory Lovins

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A B S T R A C T

The US electricity sector is undergoing a major transformation toward clean energy. In this article, I discuss several key enabling steps with Amory Lovins, whose 1976 article about the "soft energy path" was instrumental in changing public policy not only in the US but throughout the globe.

I first came to know of Amory Lovins when I was a graduate student at the University of California at Davis interning at the California Energy Commission. His article on "Energy Strategy: The Road Not Taken?" had appeared in *Foreign Affairs*. It caught my eye because the proposition it put forward seemed to reverse the conventional way of thinking about energy strategy. Sometime in the early 1980s, Amory visited EPRI where I was working and we had a lively discussion about the future of electric utilities. In the decades that followed, I have followed his writings carefully and benefited from the occasional conference. We don't always agree on everything we discuss, of course, but I always learn something new from our conversation.

I recently caught up with him in a discussion about electrification. I decided to put a few questions to him and this article evolved out of those discussions. In the article that follows, the questions are mine and the answers are exclusively his. They do not necessarily represent my viewpoint.

1. In 1976, you wrote a groundbreaking article on energy strategy, "Energy Strategy: The Road Not Taken?"[1] You made the case for pursuing a soft path in energy policy. You were met with much criticism, some of which bordered on ridicule. Yet you held your ground. How did that sea change in thinking come about among regulators and utilities?

Time, place, message, and tenacity. Then as now, it was obvious to most dispassionate observers that business-as-usual didn't work—too costly, slow, insecure, and disagreeable—but nobody had yet articulated a coherent alternative. Publishing a fundamentally new approach at that moment in an influential place (*Foreign Affairs*, thanks to Editor Bill Bundy and his wife Mary) was like dropping a seed crystal into a supersaturated solution: suddenly there's a crackling noise and the substance transforms. Then followed a year of three dozen critiques and responses, all assembled by Ray Watts into a four-inch-thick fine-print Senate hearing record.

Once the supply-side industries' initial pique abated somewhat, and their surrogates proved unable to rebut the analysis, many thoughtful industry leaders started to realize I'd suggested how they could make more money with less risk. As the dust settled about a year into the fray, Arco's Chief Economist, Dr. David Sternlight, reset the tone by writing that he for one didn't care if I were only half right—that'd be better performance than he'd seen from the rest of them. Within the next few years, many initially critical organizations were engaging me to explore how they could capture the advantages. Competition ensued.[2]

Now only the most irretrievably unreflective firms don't pay attention to the end-use / least-cost approach of asking first, "What do we want this energy for? How much energy, of what kind or quality, at what scale, from what source, will do that task in the cheapest way?" Novel concepts like comparing or competing all demand- and supply-side resources, and rewarding utilities for cutting customers' bills rather than for selling them more energy, began to appeal to regulators, spurred by allies like Ralph Cavanagh and Art Rosenfeld. States and utilities that adopted those reforms did better. The word began to spread.

2. If I recall correctly, decades ago you took on much of the economics profession by opposing the RIM test for evaluating energy efficiency programs. Many economists considered it the No-Losers test. You called it the Hardly-Any-Winners test. That was a sophisticated repositioning of the debate. Some others followed your coinage and called the RIM test the No Winners Test. Today, only one state uses the RIM test. How did that change in thinking come about?

I contributed rather briefly to that campaign, which many others ran to ground at the state level. Regulators, many of whom I'd helped teach for a decade at Camp NARUC, realized that the RIM test

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[1] https://www.foreignaffairs.com/articles/united-states/1976-10-01/energy-strategy-road-not-taken.

[2] "Soft Energy Paths: Lessons of the First 40 Years," 19 Aug 2016, https://medium.com/solutions-journal-summer-2016/soft-energy-paths-f044e7b65443

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guaranteed misallocation of capital; it would raise everyone's rates and bills equitably but needlessly. I'm delighted that almost all Commissions now agree.

A few months ago, when I gave a talk for Florida regulators and utilities, it seemed this concept was starting to gain traction there. I said if I faced the same perverse incentives that the utility executive on the panel did, I might find demand-side opportunities as small as he did—to the deep competitive disadvantage of my company and the state's economy. Folks seemed to be listening carefully. I hope regulators whose states have benefitted from replacing RIM with societal metrics will offer their Florida colleagues some friendly advice.

3. As we look at the future, what are the most effective levers for promoting energy efficiency? Utility programs, codes and standards, or market forces?

All of the above, and more, activated by smart regulation wherever possible. Start with aligning utilities' and customers' interests, so whatever delivers the cheapest and best end-use services to customers is the most profitable investment for the provider. Get and stay at the forefront of codes and standards, but recognize they often lag state-of-the-shelf and get watered down by influential laggards, so reward cost-effective overperformance and continuous improvement. Don't assume that saving more will cost more: integrative design (designing buildings, factories, equipment, and vehicles as whole systems for multiple benefits) often makes severalfold bigger energy savings cost *less* than small or no savings.[3] Nurture and reward vibrant competition and coopetition to engage many diverse actors and drive continuous innovation.

4. It has been said that the cleanest kWh is the one that is not produced. Should energy efficiency precede renewable energy in the "loading order" of resources?

That's the result you'll usually get if you choose the best buys first, require and allow all resources of all kinds to compete fully and fairly, and—an important new item—foster integrative design, so efficiency can sustain the same radical cost reductions and increasing returns that modern renewables now deliver. However, if you neglect some of these steps, some renewables in good sites may now outcompete the costlier kinds of efficiency that still use outmoded, dis-integrated, but still prevalent design methods. The result will still be much safer and healthier than acquiring fueled resources, but not as good as it could have been with a full portfolio of the most modern options for both efficiency and supply.

In other words, unsubsidized PV and wind power have often fallen through busbar costs of 5, 4, and 3¢/kWh, and in the best sites are now near or below 2¢/kWh, heading for 1¢ in this decade. End-use efficiency classically deployed technology-by-technology costs utilities an average of around 2¢ per saved kWh, plus or minus a few cents. But now integrative design can make efficiency severalfold bigger and cheaper: for example, about a fifth of the world's electricity could be saved by making all pipes and ducts fat, short, and straight rather than skinny, long, and crooked—repaying the investment in typically less than a year in retrofits, instantly in newbuilds. Yet hardly any utilities suggest or offer this option, and it's not in any standard engineering textbook, industry forecast, government study, or climate model. Why not? Because it's not a technology; it's a *design* method, and few people yet think of design as a way to scale efficiency quickly. Regulation that rewards savings achieved, not money spent or hardware deployed, could usefully add encouragement for integrative design processes, as Northeast Utilities long ago pioneered in supporting design charrettes and simulations for efficient buildings. Then they needed fewer hardware rebates because efficiency shrank or eliminated much of the equipment.

Q. What's your opinion of shared savings mechanisms for promoting energy efficiency by giving utilities a share of the societal benefits created by their programs?

Shared savings are a logical and powerful complement to decoupling profits from volumetric sales. Letting providers keep a small fraction (classically about a tenth) of what their efficiency investments save their customers gets their attention. I remember around 1992, PG&E invested $192 million in efficiency (recovered from all customers over many years) and thus saved customers several times that much. The CPUC allocated those savings 11% to the utility and 89% to the customers. The 11% reward was over $40 million that year—the utility's second-big source of profit, earned at no cost or risk to the shareholders. Canadian civil engineer John C. Fox (later Chairman of RMI) was then leading PG&E's demand-side efforts. He reported that if you produced that kind of financial performance, the CEO would call you every week to ask, "Is there anything you need?," and all the smartest people in the company would want to come work on efficiency to advance their career prospects. Such alignment of provider interests with customer interests profoundly reshapes culture and behavior.

Decoupling plus shared savings, or its functional equivalent in jurisdictions not using traditional regulation,is one of the two most important policy innovations needed for the energy transition. (The other is strong feebates—which can be size- and revenue-neutral—for at least new light-duty vehicles, arbitraging the spread in discount rate between private buyers and society; buyers can choose whatever vehicle they want, but within that type and size class, they get rewarded for choosing a more-efficient model. Otherwise, at typical consumer discount rates, whether to get an efficient vehicle looks about as unimportant as whether to buy floor mats; yet society has a vital interest in an efficient choice.)

5. What's your take on electrification and building decarbonization?

It's now really hard to make a business case for burning fossil fuels in new or most existing buildings. Combustion is so 20th-Century—an ancient practice ripe for replacement, especially now that aging gas infrastructure could be advantageously phased out rather than expensively renovated. We have better choices today than digging up and burning the rotted remains of primeval swamp goo. But our electrification design and technology choices need to be judicious, not indiscriminate.

Least-cost off-gas choices need a leapfrog from old to new end-use technologies. Miniature high-speed low-lift (13–31 C°/ 23–56 F°) heat pumps now entering the market can produce 6–15 units of domestic water-heating per unit of electricity, so a square foot of PV panel on your roof can heat much more water than a square foot of solar thermal collector. Another uncompromised Swiss technology (from Conduction AG in Basel) just tested by the California Energy Commission[4] is 2.5–4^{+} times more efficient than induction cooking, and superior in all other respects. Modern space-conditioning heat pumps are severalfold more efficient than the old commodity-grade versions, and can operate well even in the most frigid winter temperatures—down to at least –37 °C / –35 °F. Electrification, new or retrofit, should use today's best technologies and reward their rapid scaling and improvement; otherwise we'll need to retrofit them later. Let's switch technologies once, not twice. The most efficient electric technologies may also avoid costly rewiring in gas-based dwellings.

Of course, prior deep retrofits of buildings can shrink or even eliminate their equipment, saving capital cost to help pay for the retrofits, and the same in newbuilds. That's how my own 1983 super-insulated passive house/office/indoor farm high in the Colorado Rockies eliminated its heating system in temperatures that then could dip to –44 °C / –47 °F, yet the house cost $1100 less to build that way. By reinvesting the saved construction cost, plus $6000 more, I saved 90% of the household electricity use, 99% of the water-heating energy,

[3] https://doi.org/10.1088/1748-9326/aad965; please start with the 4-minute video abstract.

[4] https://fishnick.com/cecplug/Conduction_Cooktop_Analysis_Report.pdf.

and half the water, all with a 10-month payback. At that time, our electricity bill for a 4000-square-foot house was $5 a month at a 7¢/kWh tariff. (Then we went solar-PV and net-positive, running the meter far more often backwards than forwards.)

Now such passive buildings—needing no heating or cooling equipment, yet with roughly normal construction cost—are becoming common worldwide. They're the basis of many least-cost net-zero or net-positive buildings—California's 2020 standard for new houses, likely to spread across the country.

Commissions could encourage such energy-frugal designs with a sliding-scale hookup fee to connect to the electric grid (or water or sewer or other public services). The builder pays a fee or gets a rebate (together called a "feebate")—which one, and how big, depends on how efficiently the building uses those resources. (Estimate up front from the energy simulation, then true up to measured usage after occupancy.) The builder needn't apply a discount rate to compare long-run savings with possible up-front investment, nor is there a split incentive between builder and buyer or landlord and tenant: the penalty or reward goes to the party who is making the design decisions, when they're being made. Feebates can usefully combine with PACE-bond financing, which can eliminate commercial buildings' split incentive by being passed through in the tax portion of triple-net lease payments.

The next big step will be decarbonizing industrial process heat—not only by more-efficient processes for making materials like cement and steel, and by less energy-intensive alternative materials, but also by using those materials far more frugally to provide the desired services. Initial exploration shows that decarbonizing global industry by 2050 is both feasible and affordable. I suspect deeper exploration may reveal lower costs rather than modestly higher costs, partly because materials are often wasted: for example, better building design could probably save at least half the concrete and rebar they now use.

In short, every market for natural gas, from power generation to petrochemicals and buildings to factories, is under major competitive threat. I used to think gas demand's ultimate decline would lag oil's by decades. Now I think they'll be much more in step, with gas giving way sooner than expected to efficient use, renewable electricity, and direct renewable provision of heat and fuels where that's a better solution than electrification.

6. In the resource mix of the future, what should be included besides the sun and wind?

Whatever competes at fair and honest prices. That means counting methane, CO_2, and the market value of fuel-price volatility when comparing natural gas with electricity.[5] It counts any other significant, real, and quantifiable externalities for all resources. It counts the expected carbon-intensity trajectory of grid power. It counts convincingly established learning curves for all technologies. If it ascribes grid integration costs to specific technologies or projects (rather than socializing them as a system cost), it does so for all resources. (Spoiler alert: evidence is emerging that those costs may be severalfold higher for central thermal power stations than for utility-scale wind and solar—for which they are empirically very small, typically a few $/MWh.[6])

Please note that bulk electrical storage is one—currently the costliest one, though dropping a few notches lower in the coming years—of roughly *eight* carbon-free grid-flexibility resources, illustrated below. We haven't yet found a case where giant battery banks are necessary (except perhaps on a small desert island), even for 100%-renewable ERCOT power in 2050.[7] That is, although utility-scale batteries' cost has halved in the past few years, so they now beat gas-turbine peakers (at least in gas-importing countries)[8], and are often cost-effective behind the meter[9], there are even cheaper and arguably ample ways to do the same thing.

But please let me reframe your question. Nowadays we should be comparing not individual technologies but optimal *portfolios* of demand- and supply-side resources. "Clean energy portfolios"—efficiency, demand response, perhaps storage, and renewables—then outcompete new (and often existing) gas-combined-cycle virtually everywhere in the US.[9] Any utility or Commission planning to build a new CCGT can expect it to become a pre-stranded asset unable to recover its full cost. Over $70 billion worth of such US plants are still proposed just to 2025, plus, just to 2024, $30 billion worth of US gas pipelines to fuel them (and over decades, about a half-trillion dollars' worth of gas infrastructure). If these assets are built, their capital will be wasted, and the underused infrastructure capacity will raise all customers' delivered gas prices roughly 30–140% above forecast. I'd hate to be a regulator who lets that happen.

7. Why has it been virtually impossible to impose a carbon tax?

The world's fossil-fuel industries earn rents totaling several percent of world GDP. A tiny fraction of that can buy lots of politicians under our one-dollar-one-vote system that gives us the best government money can buy. The resulting immense political power has helped hold down fossil fuels' total global taxation (outside the road sector) to an average of just $3 per ton of CO_2 while they get $478 billion of annual subsidies.[10] That's buttering your bread on all six sides. It will go on until we rise up and stop it. Perhaps states will start imposing fuel taxes that offset the subsidies those fuels receive, or at least shadow-pricing fuels in administrative decisions as if they were not subsidized. If we don't know what any resource really costs, we won't know how much is enough, and subsidy politics will hide economics.

The supply industries' special political influence in the United States creates a unique politicization and polarization of climate science, which almost everywhere else is considered a scientific issue. It also encourages those who demonize government and taxes, and are not called to account for pretending to support free markets while imposing larcenous costs on others, or for opposing others' subsidies while denying their own bigger ones. Corporate socialists masquerading as free-marketeers deserve exposure. I hope all who care about markets will join me in calling for independent, impeccable, transparent assessment of all federal and state energy subsidies, so we can know who's getting what. With luck, I might then live to see the complete desubsidization of the US energy system, so all resources can compete fairly without regard to their type, technology, size, location, or ownership.

Both accuracy and rhetorical clarity would be better served if pricing carbon were described as a fee-and-dividend, with an attractive dividend rebating the proceeds to customers. Unlike a tax, this could be revenue-neutral.

Of note, our 2011 business and design book *Reinventing Fire*[11] found the US could cut projected carbon emissions 82–86% while supporting 158% GDP growth in 2010–50, $5 trillion *cheaper* in net present value than business-as-usual—*counting no carbon price* or any other externalities. The benefits would be even bigger and faster with carbon pricing. The opportunities are still greater in countries like India and China that are still building much of their infrastructure and can more

[5] https://doi.org/10.1016/j.tej.2017.06.002.

[6] https://doi.org/10.1016/j.tej.2017.11.006.

[7] An old video of how the moving parts fit together is at https://www.youtube.com/watch?v=Msg-rahFln0s.

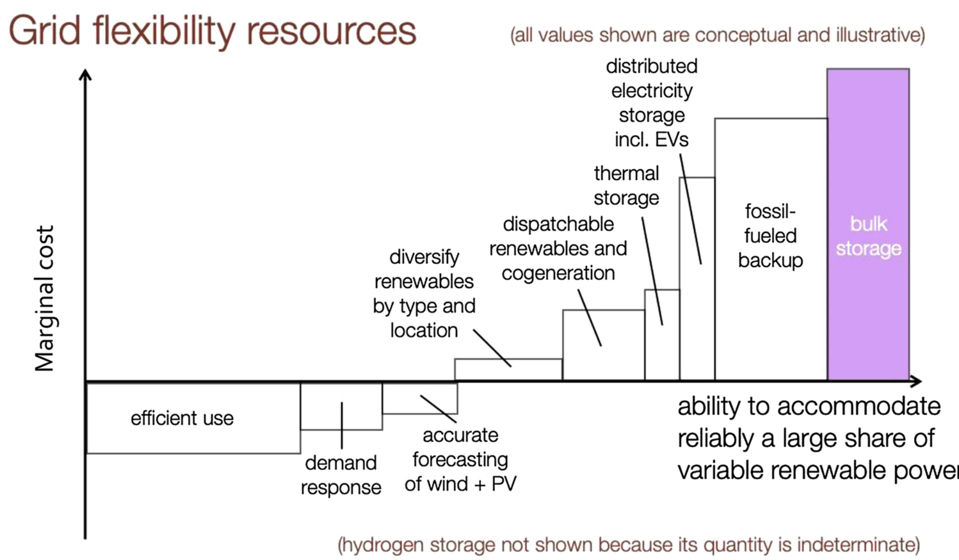
[8] https://about.bnef.com/blog/scale-up-of-solar-and-wind-puts-existing-coal-

(*footnote continued*)
gas-at-risk/. To update some data in that video, the recent annual renewable electricity fractions of domestic demand include 90% in Scotland (2019), ≥79% in Denmark (2019), 46% in Germany (2019—and 56% in the first half of 2020), 64% in Portugal (2018), and 46% in peninsular Spain (2016). None added material bulk storage.

[9] https://rmi.org/insight/clean-energy-portfolios-pipelines-and-plants.

[10] https://www.oecd.org/environmnt/governments-should-use-covid-19-recovery-efforts-as-an-opportunity-to-phase-out-support-for-fossil-fuels-say-oecd-and-iea.htm; https://www.iea.org/articles/low-fuel-prices-provide-a-historic-opportunity-to-phase-out-fossil-fuel-consumption-subsidies.

[11] Chelsea Green (White River Jct., VT); www.reinventingfire.com.



easily build it right than fix it later. And the greatest opportunity is in China because, says IEA, its generators can immediately save tens of billions of dollars a year just by adopting full economic dispatch.

8. What's your take on California's policy to require rooftop solar on all new homes? Should other states follow suit?

Good idea, if four conditions are met:

- the needed systems are small because the house is extremely efficient (long an area of California leadership, but always evolving);
- there's enough unshaded roof-space (otherwise simple local trading could even out the distribution of solar access);
- marginal cost doesn't unduly burden homebuyers because financing is rolled into the mortgage and/or avoided utility investments are reallocated to rooftops (by regulatory action or on-bill financing); and
- the resilience benefits are fully captured. All distributed generators should by default use IEEE-1547-compliant auto-islanding, so critical loads will be served with or without the grid. Commissions should encourage or preferably require such resilient hookups—or at least stop utilities from prohibiting them (based on old line-worker safety concerns that the IEEE 1547 standard has already resolved).

Commissions should also require resilient onsite PV power to enable their states' filling stations to pump gasoline and diesel even if the grid fails. Lack of that capability (a reasonable utility ratebase candidate) has been the biggest cause of slow recovery from major storms because first responders and genset owners couldn't get fuel.

9. What should be the role of load flexibility in a future world that relies heavily on renewable but intermittent sources of energy?

Please let me suggest tuning up our terms. Solar PV and wind power are not "intermittent"; they're *variable*. Their variation is highly predictable—often more predictable than electricity demand itself. The term "intermittent" is best reserved for *un*predictable (forced) outages, which are far more characteristic of large, "lumpy" thermal power plants, and costlier to manage because more capacity is lost, more abruptly, often for much longer.

Grid balancing, as I mentioned earlier, can draw on at least *eight* carbon-free categories of flexibility resources. Here's a qualitative sketch of what their supply curve could look like:

Even small-looking steps can be large. For example, the "demand response" box, when more carefully examined, turned out to be about three times as big as had been thought—in ERCOT for 2050, its comprehensive adoption could more than eliminate the "duck curve" (or in Texan, "dead armadillo curve"), cut summer daily load range nearly in half, save a fourth of nonrenewable capacity, make renewable energy a third more valuable, and pay back in about five months.[12] Today's cash-stressed utilities especially need such demand-side solutions—as ConEd is doing in Brooklyn and Queens to defer a billion-dollar investment.

Yet many regulators are still incentivizing the costliest grid-flexibility options first. A least-cost approach to such resources could probably save money and deepen resilience. It could also buy time to ripen some of the more novel grid-flexibility options—for example, better controlling buildings, with thermal time constants effectively amplified by greater efficiency, so the buildings' stored warmth and coolth can passively substitute for currently peaky heating and cooling electric loads. It's generally far cheaper to store thermal energy than electricity.

10. What should be the mix of demand-side and supply-side strategies in order to achieve a zero carbon economy?

That's an outcome of a process—market competition or its administrative proxy—rather than a starting assumption. I'd therefore focus on a transparent, fair, honest process that will yield the best and cheapest answer. I suspect that a sound process would yield more demand- and less supply-side emphasis than is now common. If indeed we're now underbuying efficiency and overbuying supply, correcting that imbalance wouldn't hurt renewables—they provided (excluding big hydro) 78% of the world's 2019 net additions of generating capacity, and will soon take the rest too. Rather, it will enable renewables to push out fossil and nuclear generation sooner, reducing risks to our health, equity, security, and prosperity. People who want 100% renewables should want strong efficiency as a partner to help achieve their renewables goal faster and cheaper. We're already underway: global fossil-fueled power generation peaked in 2018 and began its decline in 2019.

11. Do you think the next generation of customers will be even greener than the Millennials?

[12] https://rmi.org/wp-content/uploads/2018/02/Insight_Brief_Demand_Flexibility_2018.pdf

Yes—and probably even more sensitive to equity, resilience, and community choice.

12. More and more states are passing laws requiring zero carbon emissions in the power sector two or three decades out. Are you optimistic that most states will have attained zero-carbon status by 2050?

I'm neither optimistic nor pessimistic. Both those simplistic attitudes treat the future as fate, not choice. They don't take responsibility for creating the future we want. Rather, I live and strive in a spirit I call "applied hope."[13]

A new study shows[14] how the United States could cost-effectively make its power system 90% carbon-free by *2035*, not 2050. Vice President Biden's climate policy includes a similar goal. Indeed, unsubsidized renewables are now the cheapest source for bulk power in 85% of the world, soon essentially all.[7] Operating coal-fired power stations plants is now so widely uneconomic that replacing them globally with new renewables (not counting potentially even-cheaper efficiency) would be cost-neutral in two years, and within five years would save more than $100b/y—far more than it would cost to ensure a just transition for workers and communities.[15] Markets are forward-looking and see this coming. No wonder the US coal industry has lost 99% of its value.

13. How do you assess the prospects for civilian nuclear energy?

New nuclear power plants have no business case anywhere in the world, with any current or proposed size, technology, or fuel cycle, so the nuclear industry is in slow-motion commercial collapse and needs an orderly terminal phase.[16] Indeed, phasing out existing nuclear plants (rather than piling on new subsidies that threaten to destroy the ISO/RTO market system) could reallocate their saved operating costs to buying even more least-cost carbon-free resources and saving more carbon sooner.[17]

Nuclear power has proven irrelevant even in Japan, long one of its biggest users and most ardent advocates.[18] In the decade since the Fukushima accident, electricity savings and renewables offset the reduction in nuclear share from 25% to 6% while slightly decreasing fossil-fueled generation. The renewable share rose from 11% to 19% despite the national government's ingeniously opaque efforts to suppress it (especially wind power) to try to protect utilities' legacy assets from competition. The remaining nuclear plants are scarcely worth restarting. Japan is starting to realize that although poor in fuels, it's exceptionally rich in renewables, efficiency, and ability to exploit both more fully where fair competition is allowed. So is the United States.

Germany, too, has used efficiency and renewables to displace nuclear *and* coal-fired generation and reduce its CO_2 emissions[19] —contrary to what a widespread, stealthy, and highly successful disinformation campaign has misled many usually well-informed but apparently not German-reading journalists into writing. Caveat lector.

14. How do you think the COVID-19 pandemic could affect the electricity sector?

As the smoke slowly clears from the wreckage of 2020 cashflows and investment plans, a transformed competitive landscape will emerge. Renewables are the only energy technology expected to show global growth this year. If it's a normal hydro year, total renewables will have soared by year-end from 26% to nearly 30% of global electricity. Already in 2019 they took more than all the global growth in electricity demand, so fossil-fueled generation peaked in 2018 and began its downward journey in 2019; in the first half of 2020, global coal power capacity fell for the first time. In the US, total renewable use surpassed total coal use for the first time in over 135 years. It's quite possible that 2019 will turn out to have marked global peaks in both oil and fossil-fuel use, because by the time demand recovers, to the extent it does, renewables will have grown enough to supply all incremental demand. That prospect has triggered massive capital flight from the fossil-fuel industries—reinforcing itself by weakening incumbents' capital and talent recruitment and their political clout. The effects will be lasting and profound. Utilities should align their strategies, and encourage politicians to align public recovery investments, with the new business opportunities and public benefits that the pandemic will accelerate.

The pandemic may speed and reinforce, but won't reverse, this fundamental strategic reality: Customers are figuring out that they can use less electricity far more productively and timely, make their own, and even trade it with each other. It's generally wise to sell customers what they want before someone else does. All the rest is detail.

Physicist Amory B. Lovins, Cofounder and Chairman Emeritus of Rocky Mountain Institute, has advised over 100 utilities and many regulators, policymakers, and business leaders worldwide, designed numerous super-efficient buildings, vehicles, and factories, taught at ten universities, written 31 books and over 690 papers, and received many top energy and environmental awards.

Economist Ahmad Faruqui is a principal with The Brattle Group. He has advised more than 150 clients on five continents on matters pertaining to energy efficiency, demand response, electrification, distributed energy resources and rate design. He has published more than a hundred articles on energy economics in trade and professional journals and co-edited four books on electricity pricing, customer choice and industrial structural change.

Dr. Ahmad Faruqui has over 40 years of experience working on issues related to customer engagement, including rate design, load flexibility, distributed energy resources, demand forecasting, and electrification. In his research and consulting career, Dr. Faruqui has worked for over 150 clients on five continents, and has published more than 100 papers on energy topics in peer-reviewed and trade journals. His work has been cited in *The Economist, Bloomberg Businessweek, and Forbes,* and he has appeared on NPR and Fox Business News. He has provided expert testimony, appeared before commissions, and presented to governments across the globe. Dr. Faruqui has taught economics at three universities over a seven-year period and has delivered guest lectures at a dozen more universities, including MIT, Northwestern, Stanford, and UC Berkeley. Dr. Faruqui obtained his Ph.D. in Economics at University of California, Davis and M.A. in Agricultural Economics and B.A. in Economics, Mathematics, and Statistics from University of Karachi.

[13] https://medium.com/@amorylovins/applied-hope-8968f9d196d3.

[14] www.2035report.com.

[15] https://rmi.org/insight/how-to-retire-early/.

[16] www.worldnuclearreport.org, *World Nuclear Industry Status Report 2019.*

[17] *Id.* At pp. 218–256; https://www.forbes.com/sites/amorylovins/2019/11/18/does-nuclear-power-slow-or-speed-climate-change/; https://www.rmi.org/decarb.

[18] https://www.renewable-ei.org/en/activities/column/REupdate/20200625.php;details at https://www.renewable-ei.org/pdfdownload/activities/NuclearPowerJapan_202007.pdf.

[19] http://www.energyintel.com/pages/worldopinionarticle.aspx?DocID=1077081.