The Seven Technology Disruptions Driving the Global Energy Transition: A Primer

Why Coal-Fired Power Generation Is in Decline

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Introduction

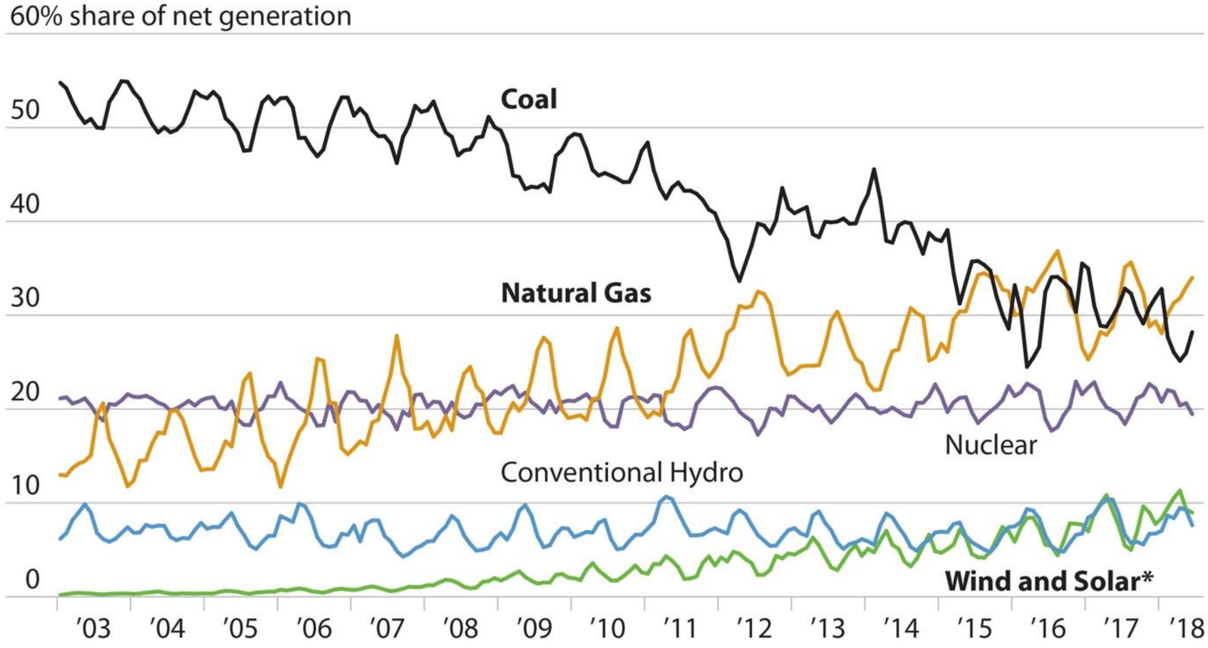
The mix of fuels used for generating electricity around undergoing a fundamental global change. Coal, which ushered in the electric age over 140 years ago and has been the dominant fuel for electrification until only recently, is now being rapidly replaced by natural gas, wind and solar as a worldwide push for electricity modernization intensifies.

At the same time, economic growth in many nations is no longer tied to increases in the consumption of fuel, as energy efficiency has increased and as the sectors leading economic expansions are less energy intensive than the heavy industries of the past.

A third trend is also gaining ground: "The electrification of everything," where electricity—rather than other forms of energy—is powering more and more aspects of commercial, industrial, and consumer life. This trend is seen most obviously in transportation, where the impact of electric vehicles is still small but is on course to completely transform the sector in the coming years.

Share of U.S. Electricity Generation, Electric Power Sector, by Fuel

Coal's share as a fuel for electricity generation has fallen sharply over the last 15 years as natural gas, wind, and solar have gained market share. Hydro and nuclear have remained relatively unchanged over the same period.



Source: Energy Information Administration

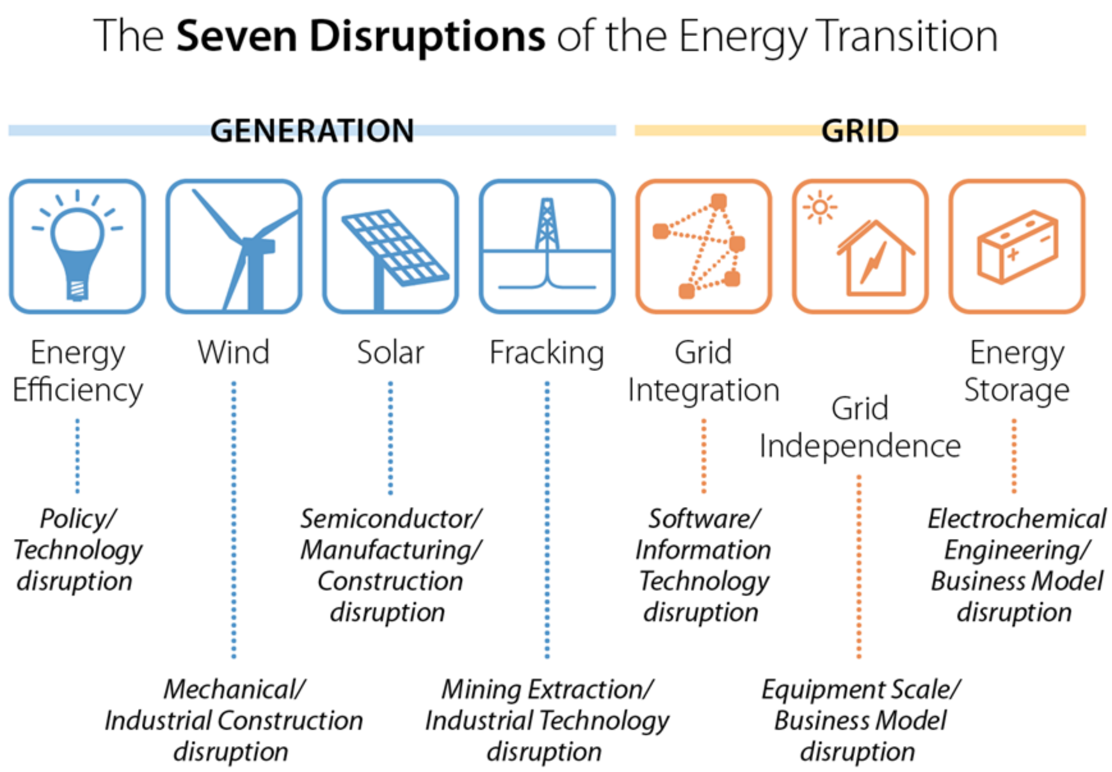
*Utility-scale only

The chart above shows how—even with most coal produced in the U.S. going to the electricity sector—power generation is becoming less and less dependent on coal.

Natural gas and renewables are gaining market share, as coal's footprint shrinks and as contributions from hydro and nuclear power remain more or less flat. These trends combined—the rise of renewables and natural gas, the decline of coal, the relative stability of hydro and nuclear—are collectively driving the transition in electricity generation and distribution.

But the energy transition described here is about more than just natural gas or renewables replacing coal: IEEFA is following seven fundamental technology disruptions that are driving this transformation. Significantly, all of them are contributing in different ways to a terminal decline in coal use, even though each is at a slightly different stage of development.

Four of the seven disruptions are primarily generation-side disruptions; three are grid-side.



The Four Generation-Side Disruptions

One: Energy Efficiency

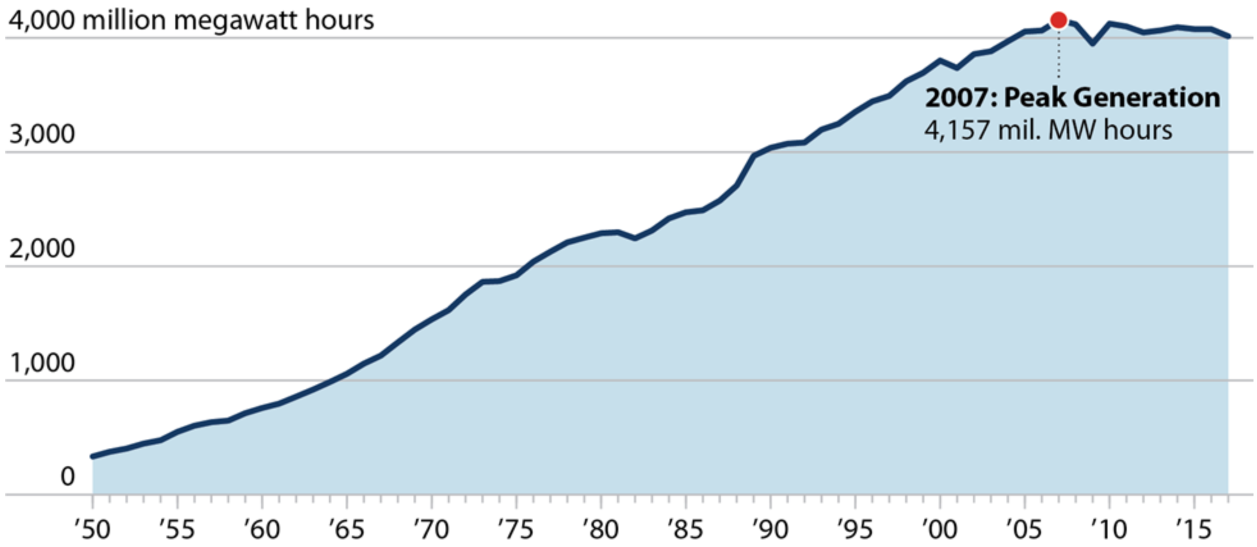
Energy efficiency is the “quiet disruption.”

In the U.S., electricity demand has been flat for a decade despite an ongoing economic expansion. This is the result in part of more efficient appliances, machines and lighting, changes all spurred by energy policy initiatives from years ago that are now paying off. Demand is flat also because the economy has become less energy intensive, as heavy industry and manufacturing have become more high-tech and efficient, and as the overall economy has become more service-sector driven than it used to be.

Taken together, these phenomena help explain the growing disconnect between GDP growth and energy use not just across the U.S. but in many economies around the world, even during the past decade or so of significant global economic expansion.

U.S. Net Generation of Electricity, 1950-2017

Decades of growth in electricity use ended in 2007, and demand has been flat to down ever since.



Source: Energy Information Administration

Two and Three: Wind and Solar

The rise of renewables—specifically wind and solar—is often seen as a single disruption, but *should* be seen as two distinct disruptions, each driven by different kinds of technology advances.

The wind industry, which is nearly a decade ahead of solar in terms of its market share of generation, can be considered a mechanical and industrial-scale construction disruption. Giant individual turbines, rated in megawatts, sit atop 30-story towers of steel, powered by precisely-built composite blades that are typically some 150 feet long each, and that are deployed in "farms" that can stretch for miles across rural landscapes. Thousands of turbine towers have been erected in recent years, mostly across the windy Great Plains, from Texas—with nearly 13,000 turbines alone—to North Dakota.

As a result, wind now accounts for nearly 9 percent of all the power generated in the U.S. during some spring months, up from just 1 percent in 2007, and is continuing to grow.

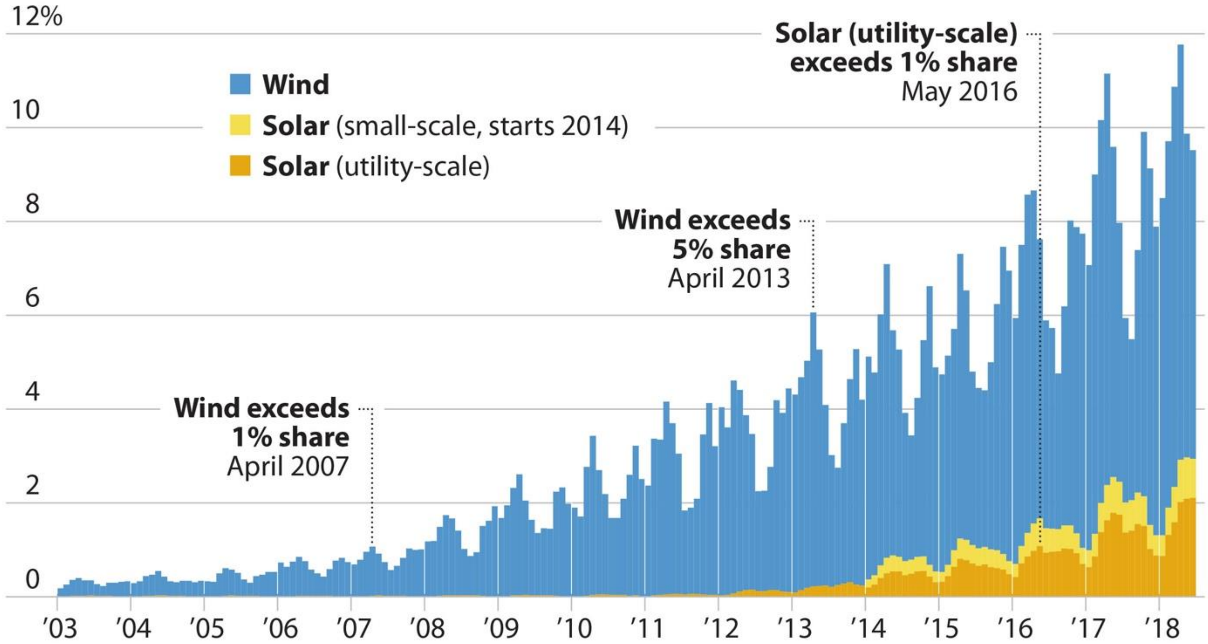
Solar photovoltaic, or PV, cells, by comparison, typically use a semiconductor manufacturing process like that used for computer chips, and the solar industry continues to see similar sharp cost reductions and increases in efficiency. Assembled into panels slightly smaller than a sheet of plywood, solar cells are being deployed anywhere from just a few at a time on residential rooftops to vast, utility-scale arrays that use tens or even hundreds of thousands of panels. The technology is advancing so quickly that in some places in the U.S., new solar power is already cheaper than power from natural gas.

Here too, the rapid growth of installations has led to a surge in solar's share of generation: for utility-scale projects, it has doubled from 1 percent in May 2016 to over 2 percent in April 2018. Add in small-scale residential solar, and solar's market share rises to 3 percent.

Even so, both solar and wind are in their early ascendance.

Wind and Solar Share of U.S. Electricity Generation

Wind and solar generation has been growing relentlessly as costs for these renwables have fallen sharply; grid operators have mastered integrating them; and utilities have increasingly embraced them.



Source: Energy Information Administration

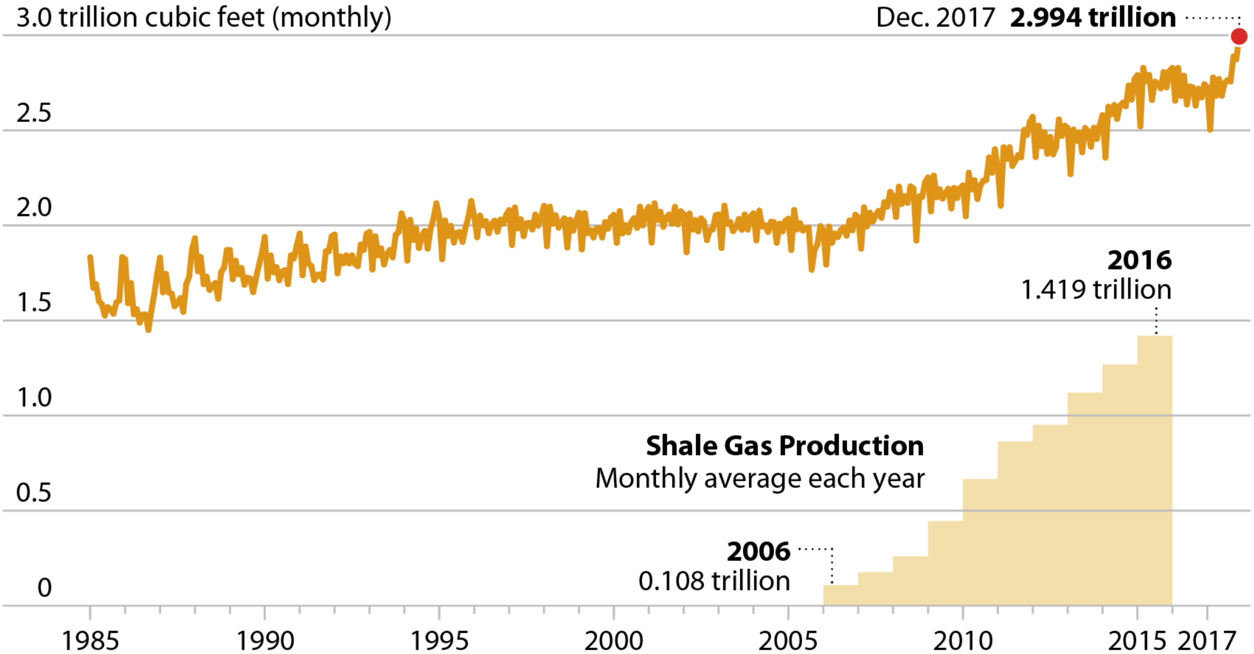
Note: Share of generation for all sectors

Four: Natural Gas from Hydraulic Fracturing

The fourth type of electricity-generation disruption comes as a result of the now-dominant use of horizontal drilling and hydraulic fracturing (known as fracking) for natural gas and oil production, a disruption that—alongside the rise of renewables—has driven down the price of electricity generation and made coal-fired generation uncompetitive.

U.S. Natural Gas Production, 1985-2017

After about a decade of flat natural gas production (1995-2005), rapid adoption and technical advances in the use of hydraulic fracturing in shale formations led to a surge in supply and low prices.



Source: Energy Information Administration

Fracking is the main reason for the rapid growth in natural gas production since the mid-2000s. In addition to being used to extract natural gas, the method is also used for oil production, which can produce natural gas as a by-product. As recently as 2004, very few new oil and gas wells in the U.S. used horizontal drilling and hydraulic fracturing; by 2016, 70 percent did. The rapid uptake of this technology has opened up vast new reserves and significantly raised production.

Because of this growth, natural gas prices have remained low, severely undercutting the economics of coal, and prices are expected to remain low for a number of years. Power generation markets have responded: in 2016, natural gas displaced coal as the primary fuel for electricity generation, and it continues to gain market share. This year alone, power plant operators are expected to bring 20 gigawatts of new natural gas-fired capacity online, according to the Energy Information Administration (EIA); in contrast, IEEFA estimates that over 15 gigawatts of coal-fired capacity will be retired.

The Three Grid-Based Disruptions

One: Grid Integration

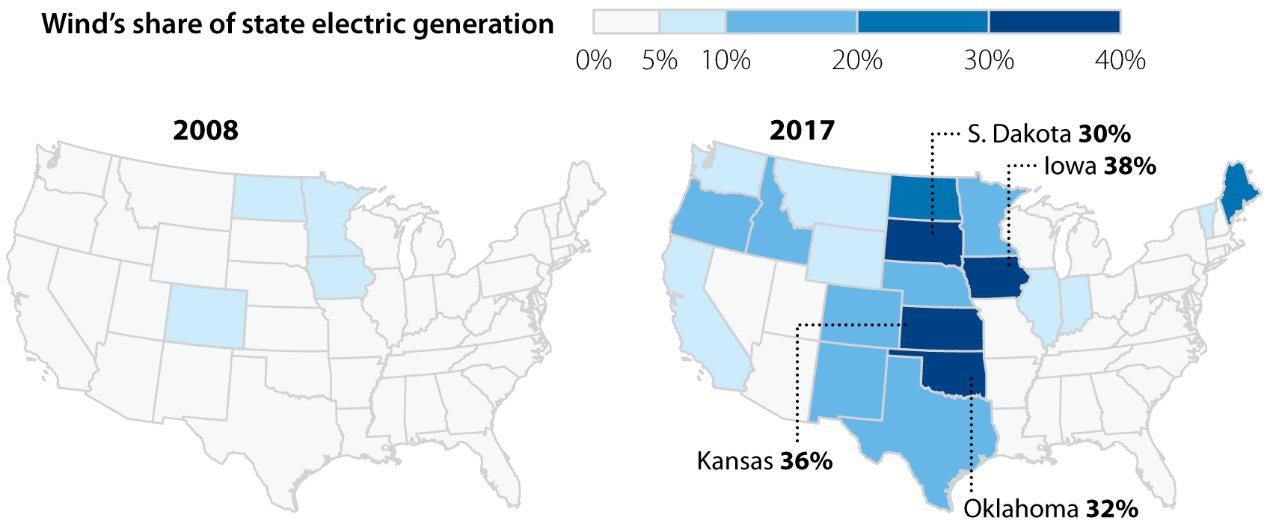
Major advances in grid management have allowed the seamless integration of thousands of utility-scale wind and solar plants; enabled a far higher share of renewables than was forecast even a few years ago; and facilitated greater flexibility in fuel switching by utilities.

Wind now contributes from 30 to 40 percent of annual generation in four Great Plains states, and contributes at least 5 percent of annual generation in 20 states. Even at these levels, curtailment of renewables has been very low—which occurs when too much renewable energy is being generated to be absorbed by the grid—and grid operators say that in fact more can be accommodated. Nearly all of this growth has occurred in the past decade.

These annual figures—while impressive—obscure even more impressive monthly, daily, and hourly grid integration levels. Iowa has generated as much as 64 percent of its power from wind in a single month, while Texas, the country's largest electric market by far, surpassed 50 percent during peak wind hours last October. This spring, California also briefly hit the 50 percent mark—with solar.

Rapid Growth of Wind Power Generation

Wind power has grown enormously over the last 10 years. In 2017, wind's share of electric generation was over 10 percent in 13 states — up from zero states in 2008.



Source: Energy Information Administration

Two: Grid Independence

As wind energy and large-scale solar have become an industrial presence, the ability of individual consumers and businesses to generate power or reduce or adjust their individual demand has also been growing rapidly.

In nearly every situation, these customers are still connected to the grid, but now have far greater control of their power through net metering, demand response, behind-the-meter generation storage, and from a growing list of other methods.

One indication of grid independence can be seen in the growth of small-scale solar, which in recent months has come close to 1 percent of all electricity generated nationally. But that figure understates the impact that all of the options consumers and businesses now have, starting first and foremost with better real-time information on their power use and power prices, and supported by constantly falling costs to install and manage their own custom power solutions.

Three: Storage

The final major disruption, still in its infancy but growing rapidly, is battery storage.

Storage offers a myriad of potential benefits across the entire electric-market ecosystem, for everyone from homeowners to the largest utilities. That versatility is pushing the pace of innovation, cost reduction, and implementation far faster than most power-industry experts predicted—a typical indication of a major technological disruption. Among the most significant impacts of storage are the time-shifting effects for variable renewable generation, especially solar, from high-generation/low-price periods to high-demand/high price peaks. Storage also helps support grid resilience and stability; it can replace the need for expensive and little-used "peaker" power plants; and it can be managed like a virtual power plant by utilities while simultaneously being a backup power source for homeowners.

Like other, more conventional forms of demand management, storage is likely to help keep overall electric prices lower. But its growing availability and use will also diminish price spikes at times of peak demand simply because many more power providers will have the ability to sell power into those high-price periods.

Electrification is coming to transportation too. While the public focus remains on how every major auto manufacturer is developing or expanding their line-up of electric vehicles, this disruption may be felt first with urban electric buses and commercial tractor-trailers, where fuel costs are significant and fleet managers can take advantage of low-priced charging times and potential grid value of storage. The impact, though, will extend from electric bicycles and scooters to electric airplanes.

Battery storage's biggest impact may ultimately be the electrification of transportation. At present, it is unclear what net effect storage will have and what interplay it will create within power markets. Depending on how electric vehicles' charging needs and storage capabilities are managed, storage could have far-reaching consequences for everything from the growth of power demand to grid stability and fuel mix.

Conclusion: A Bleak Outlook for Coal-Fired Generation

The seven disruptions described here demonstrate the breadth and depth of the technological changes transforming the economics of the electric power industry.

Each of them, in their own way, is increasing the price competition facing the thermal coal industry. All of these disruptions are contributing to an historic collapse in the relationship between coal and the power industry.

Taken together, these disruptions signal a permanent structural decline for coal in the U.S., and a future in which no new coal plants will be built the U.S.; retirements among the existing, aging coal power fleet will continue unabated; and a constant restructuring of the coal mining industry is inevitable in the face of a shrinking customer base, massive overcapacity, and intense competition.

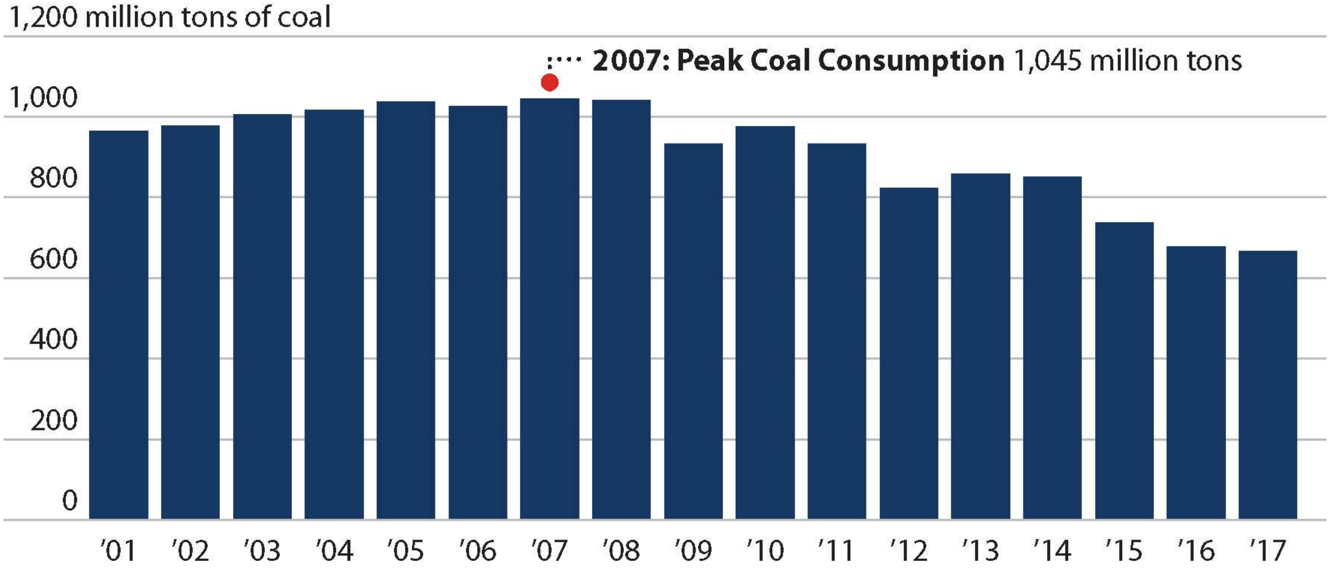
In addition to these clear-cut economic drivers, there is a more subtle one that will continue to significantly influence the energy transition in the U.S.: the asymmetric relationship between the coal industry and utilities. Today, most of the coal mined in the U.S. goes to generate power, but most of the power produced in the U.S. is no longer generated from coal.

This is of note because most coal mining companies do not own stakes in power producers, and most power producers do not own stakes in coal companies. For power producers, this reality simplifies the economic decisions around closing coal plants—if a plant cannot turn a profit using coal, it only makes sense to shut it down and switch to a cheaper form of power production. Coal companies, on the other hand, have little recourse beyond turning to a limited and fickle export market, because industrial, commercial, and residential use of coal has already all but disappeared.

More bad news for coal is rooted in the way utilities have already cut their coal-fired generation capacity. Most of the units retired in recent years were among the smallest and oldest ones operating. This is an outcome that made economic sense, assuming the remaining large plants would stay competitive based on scale and efficiency. But because the energy transition is disruptive rather than gradual, and because costs for renewables and natural gas have fallen so fast, some of the biggest plants have now become uncompetitive

U.S. Coal Consumption for Electricity Generation, 2001-2017

Coal consumption has fallen sharply in the past decade as disruptive energy technology trends have taken hold.



Source: Energy Information Administration far sooner than expected. These include coal-fired plants like the Navajo Generating Station

in Arizona, Bruce Mansfield Power Plant in Pennsylvania and W.H. Sammis Power Plant in Ohio, all of which are now scheduled to close over the next few years.

Other factors working against the U.S. coal industry include export limitations because of port constraints, a global trend in coal phase-outs that is gaining momentum, and the fact that "clean-coal" and carbon-capture experiments have repeatedly failed.

The seven disruptive trends described in this paper have become powerful, market- and technology-driven economic forces transforming not just electricity markets, but every aspect of how electricity is generated, stored, and used. Together, they are driving a fundamental, long-term energy transition that favors lower-cost and cleaner sources of generation, especially renewables, while relentlessly driving out higher-cost and more polluting fuels like coal.

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