Change and the Heartland

How Climate Change Will Affect the Midwest

Big issues, bite-sized lessons

What is the Future of Electricity in the U.S.?

ILLINOIS
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

> Key Term
>
> **Smart Grid**
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> With our current electrical grid, you can be either a consumer or producer. Producers are centralized power plants, and consumers are the millions of buildings they serve.
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> With a smart grid, digital technology would allow everyone to be a producer and feed surplus electricity into the grid. People with rooftop solar panels or wind turbines could sell excess power back to their municipalities. The grid would also increase reliability and transparency while reducing the costs of energy distribution.

Most people give little thought to the source of the electricity that comes out of the outlet. And why should they? The American electric power grid has been designed as the ultimate in plug-and-play convenience—just flip a switch and the light comes on. Aside from the monthly bill and the occasional blackout, electricity is easy to take for granted.

Yet lately it is hard to open a newspaper without seeing references to the changes brewing in the electric industry—cap-and-trade, renewable electric energy sources, global climate change, plans to phase out incandescent light bulbs, cyber security, and the so-called "smart grid."

Top Engineering Achievement of the 20th Century

The humble electric outlet is a gateway to one of the most complex and largest entities ever created. Except for a few islands and other isolated systems, the entire electric grid in North America is really just one big circuit. It has billions of individual electric loads, tens of millions of miles of wire, and tens of thousands of electric generators. Electric lines operating at up to 765,000 volts (more than 6,000 times the typical household value of 120 volts) allow electricity to be transferred hundreds of miles with very low losses.

The intricacy of this grid was recognized in 2000 by the U.S. National Academy Engineering as the top engineering achievement of the 20th century, beating out the automobile, the airplane, and electronics, among other competitors.

Reliability, Economies of Scale, Vulnerability, and Price Volatility

An interconnected electric system has two primary benefits: reliability and economics. An interconnected grid with thousands of generators means that when even the largest generator fails, the lights stay on. From an economic perspective it also means that utilities can trade electricity, taking advantage of lower cost generation that may take place hundreds of miles away. Large electricity markets, such as the Midwest Independent Transmission Operator covering 13 states and the province of Manitoba, allow electricity to be traded in real time, similarly to what occurs on Wall Street with stocks.

But this high degree of connectivity has a detrimental side effect: if something goes wrong, the results can quickly be felt over a large area. The blackout on August 14, 2003, which affected more than 50 million people in eight states and the province of Ontario, provided ample evidence that widescale blackouts are not a thing of the past. Electricity markets can also fail through high price volatility. For example, in June

Will Coal Be the Fuel of the Future?

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1998, the wholesale price of electricity in Illinois soared more than 100-fold, increasing from typical values per kilowatt-hour of perhaps 5 cents up to $7.50. A much longer-lasting market problem occurred in California in 2001, resulting in the bankruptcy of the state's largest utility, Pacific Gas and Electric.

Electricity Created on Demand and Delivered Milliseconds After Generation

These problems arise because of some of electricity's unique properties. For example, batteries provide a convenient way to store the electricity needed to run cell phones and flashlights, but there is no inexpensive means for storing large amounts. So pretty much second by second, the electricity created by generators must equal that used by all the consumers on the grid (called the load).

The grid thus represents the ultimate in "just-in-time" manufacturing. Because electricity moves at nearly the speed of light, it's always delivered to the outlet within milliseconds of having been created in a generator. This flexibility is important because there is a continual need to keep total generation in balance with total load. Fortunately, the total load on the electric grid is relatively stable, since devices being turned on are balanced somewhat by others being turned off. But over the course of days, weeks, and seasons there can be large variations in total electricity consumption—the load on a hot summer afternoon might be several times what is at 3 a.m. on a Sunday morning in fall.

Engineers Cannot Control the Path Electricity Takes from the Generator to the User

Another peculiarity of electricity is that, with few exceptions, there are no mechanisms to directly control how electricity flows from generator to consumer. Engineers can monitor how it flows through the high-voltage electric grid (known as the transmission system), but there is no means to change the flow of electricity on an individual transmission line, short of totally disconnecting the line. The adage that electricity takes the path of least resistance is somewhat misleading, because electricity doesn't flow along a single route from the generator to the load. Rather, it spreads throughout the transmission system as dictated by what engineers call impedance. Also, when one line fails, say due to a lightning strike, it is automatically taken out of service in less than a blink of the eye, and just as fast the electricity automatically redistributes itself to the other lines.

The Midwest Independent Transmission System Operator Control Center controls the grid in much of the Midwest, including most of Illinois.

Courtesy of Midwest Independent Transmission System Operator, Inc., Carmel, Indiana www.midwestmarket.org

Power Lines Often Run at Capacity Because Permission to Build New Lines Takes Years

Finally, the electric transmission system has only a limited capacity for transferring electricity. Just like an extension cord can overload when carrying too much electricity, transmission lines have limitations. Because it's difficult to gain permission to build new lines, the transmission system is becoming increasingly loaded just due to growth. It often makes economic sense to operate that increasingly loaded grid as close to its limit as possible to take advantage of more inexpensive electricity generation.

40% of Electricity from Coal, 2% From Renewables

On the supply side, about 40% of the total energy used in the U.S. comes by way of electricity, a percentage that has been gradually increasing. In 2008, we got almost half of our electricity from coal, about 21% from nuclear, 19% from natural gas, and 6% from hydroelectric. While some renewables are growing rapidly, their overall percentages are still relatively small, with wind supplying slightly more than 1%, wood and other biomass about 1% (a number that has decreased over the last decade), and solar less than 0.01%.

But these percentages vary widely by state. Indiana gets more than 95% of its electricity from coal, while in Illinois, coal and nuclear dominate, supplying 95% of the total in roughly equal shares. California gets essentially none of its electricity from coal, while Oregon and Washington get 60% and 73%, respectively, from hydro.

Why the differences? Obviously, hydro is only practical where there is lots of water, plus large differences in elevation in which to construct reservoirs. States with large coal reserves or good railroads have tended to use coal since to date it has been a relatively inexpensive source. The same is true for natural gas and pipelines. Distribution of nuclear power depends on historical attitudes of utilities and their states—in Illinois, Commonwealth Edison invested heavily in nuclear during the 1970s and 1980s, whereas Indiana utility companies did not.

Coal Accounts for a Third of All CO_2 Emissions from All Energy Sources, Predominating in the Midwest and South

The power industry produces about 40% of human-produced emissions. But these vary substantially by fuel type. Nuclear, wind, solar, geothermal, and hydro power create essentially no emissions. Overall, the burning of coal for electricity generates more than 85% of total electricity emissions, and hence more than a third of the total for all energy sources. Any attempt to reduce carbon dioxide emissions will need to involve coal generation.

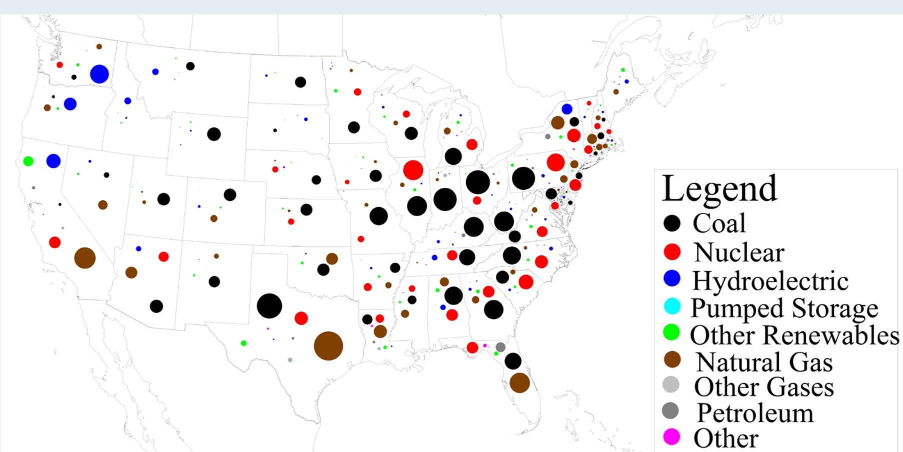
There are no quick, inexpensive, short-term fixes to this issue, at least not for the Midwest. Some states, including Illinois, have a lot of capacity for natural gas generation. In fact, Illinois has more natural gas capacity than nuclear, and almost as much as coal. So a fast, but certainly not inexpensive, way to reduce carbon dioxide emissions would be to use more natural gas generation. But some states, including Indiana, Missouri, and Ohio, do not have enough capacity to supplant a large percentage of their coal usage. Natural gas generation also tends to be more expensive than coal, and substantially more expensive than nuclear. Of course, more natural gas generation could be built, but the cost depends on highly volatile fuel prices. With prices currently below $4/Mbtu, natural gas generation can be quite competitive with coal. But just last year natural gas prices were three times as high and could rise again with increased demand.

A second potential approach to reduce emissions would be to import more electricity from states with alternative generation sources. However, while the high-voltage transmission grid does allow for such transfers, the capacity to move power long distances is actually quite limited. The system was designed to meet the needs of local utilities, to move electricity from their generators to their customers. Illinois might be able to import 15% of its total electric usage, but such imports would need to come from neighboring states, which also depend on coal. New long-distance transmission lines could be built, but quite a few lines would be needed, and getting approval for any new line takes years.

Wind Power Requires a Lot of Space; Solar Is Expensive and May Be Years Away

Of course we can build new generation, and as a glance around the midwestern countryside indicates, wind is a rapidly growing, carbon-free, relatively economic source of electricity. But it would take a lot of wind—and lots of land and quite a few years—to substantially replace our existing fossil fuel generation. A ballpark figure is that each 10 to 15 megawatts (MW) of wind capacity requires about 1 square mile of land. While most of this land can still be farmed, and payments to landowners can be significant, a peak load of about 30,000 MW in Illinois alone means a lot of countryside dotted with wind turbines. As of June 2009, Illinois had 915 MW of wind capacity, Indiana 531, and Iowa 2,883. Also, wind turbines can generate only when the wind is blowing, and the highest loads often occur on days with very little wind.

The renewable energy source with the most potential is solar power. But while costs have been decreasing, solar power remains quite expensive compared to other alternatives. It will probably not make a substantial contribution to our total electric consumption for at least a decade.



Energy generated per state by various methods. Coal predominates in the Midwest.

With Help of Smart Grid, Conservation a Good Start

Consumers can make a difference, too. One way to achieve lower carbon dioxide emissions would be to simply use less electricity. This goal could be achieved through multiple means, including simple ones, such as turning off unused lights and buying more efficient light bulbs and appliances. Educating consumers about their true energy usage minute-by-minute could also prompt them to conserve. This could be done with a smart grid, with digital meters showing consumers their exact energy usage instantaneously. Some experts estimate that savings of 5% to 15% are possible.

Whether such savings can actually be achieved by most people over the long run, as opposed to by the dedicated few who spend the time to monitor their electric usage, is yet to be seen. Some of these purported savings can be easily achieved with existing devices, such as programmable thermostats, that have been available for decades. And some strategies may actually be counterproductive. For example, turning off the basement dehumidifier can result in short-term savings on the power bill, but the practice could be detrimental to the long-term health of a house and its occupants. Added to this is the possibility that the new smart meters could become a target of choice for hackers. The "cyber vulnerability" of the electric grid, from the meters to the overall control systems, is an area of growing concern.

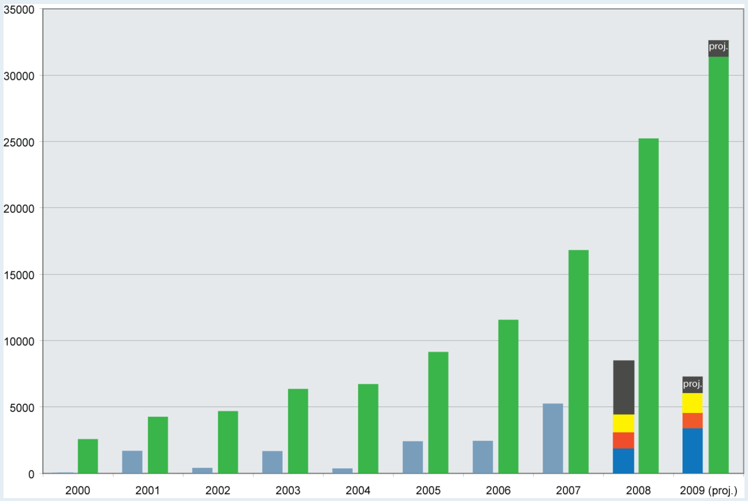
Increasing Costs Could Provoke Conservation

The more challenging but ultimately quite effective strategy for decreasing consumption of electricity is to increase its cost. Basic economics tells us that the more something costs, the less we use. The ultimate premise behind cap-and-trade legislative initiatives is to reduce usage of carbon dioxide–producing fuels such as coal by making them more expensive. How much financial pain needs to be inflicted depends on how quickly the carbon dioxide emissions are to be reduced.

Small Solar Generators May Be Installed at Homes, But Probably Not Wind Turbines

Finally, in an ironic twist, the electric power industry may be moving back to where it began in the 1880s, with small generators supplying a handful of customers. Distributed generation, often in the form of rooftop solar or a backyard wind turbine, is a small but growing source of electricity. While there is certainly gratification for some in reducing the monthly electric bill, the large upfront costs of this power generation can make for long payback periods, even when installation is coupled with tax breaks that may cover more than 50% of the total cost.

Wind Power Generated 30,000 Megawatts in 2009



Graphic courtesy of AWEA (www.AWEA.org).

Whether these individual generators will ever make economic sense for most homeowners depends on the degree of economy of scale present, keeping in mind that the total losses in moving electricity from distant generators to a customer's house seldom exceed 20%. With wind there are substantial economics of scale, since larger turbines cost less to build per unit of energy, and the wind is substantially faster at 200 to 300 foot hub heights of MW-size commercial wind turbines (power output rises with the cube of the wind speed). With solar photovoltaics there is substantially less economy of scale, so rooftop installations may eventually become competitive.

So what's in store for the electric grid? With large fluctuations in fuel prices, pending carbon reduction legislation, uncertainties about new technology, and a ballooning federal deficit, it is really hard to say. It is certainly an exciting time to be an engineer in the electric industry, and our university enrollments in this field are at record levels. But as consumers in the Midwest we may be in for some rocky years; someday we may look back fondly on the low electric rates we enjoy today.

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