THE CASE FOR BASELOAD

AN ENGINEER'S PERSPECTIVE ON WHY NOT JUST ANY GENERATION SOURCE WILL DO WHEN IT COMES TO THE SYSTEM'S CAPACITY, STABILITY, AND CONTROL.

BY CHARLES E. BAYLESS

The electric system is more than just the delivery of energy—it is the provision of reliability. First, the system must have capacity, that is, the capability to furnish energy instantaneously when needed. The system also must have frequency control, retain stability, remain running under varied conditions, and have access to voltage control. Each of those essential services for reliability must come from a component on the system. Those components are not free, and they don't just happen. They are the result of careful planning, engineering, good operating procedures, and infrastructure investment specifically targeting these items.

A baseload solution: integrated coal gasification, combined-cycle technology, with carbon capture and storage.

Courtesy: GE

Baseload generating plants—large-capacity plants used to meet a region's continuous energy demand, producing energy at a virtually constant rate—currently provide those elements of reliability. The great majority of these plants are nuclear and coal-based, with a minority comprised of (mostly) combined-cycle natural gas and large hydro. Baseload generation is important because it is low-cost and the first source to be dispatched. It is even more important because it provides the vital services the system requires.

In a real sense, baseload generation is inseparable from the system itself, physically, technologically, and economically.

HAVING BACKUP CAN SOMETIMES MEAN THE DIFFERENCE BETWEEN SUCCESS AND FAILURE.

In today's debates on energy, energy independence, and the nation's fuel mix for electricity, the basics of baseload often play a muted role. We are looking for solutions to global climate change, the largest environmental problem we have faced; it is imperative that we reduce greenhouse gas (GHG) emissions; and we must find solutions to other environmental problems, as well. And there are many solutions, with generating technologies that are either here today or near target. Natural gas, with lower GHG emissions than coal, has found promise not only in imports of liquefied natural gas, but also in new shale-oil discoveries. Wind- and solar-generated electricity uses fuels that essentially are free. Wind generation has led all other construction in the last few years; and solar plays a growing role from the California desert and rooftops to the tops of poles in New Jersey. Small hydro and renovations of large hydro are taking advantage of another low-cost fuel. Geothermal and biomass technologies play a greater role. The role of distributed

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Courtesy: AEP

System foundations. Good examples are PG&E's Diablo Canyon nuclear station in California (left) and AEP's coal-based Welsh plant in Texas.

energy as a way to help with demand response and forestall construction of central-station generation is coming about. The technologies for energy storage—through batteries, compressed air storage, and other evolving technologies—have great promise, too. And we've only begun to tap the well of energy efficiency.

But all generation technologies play a role in addressing GHGs, reliability, and cost. Part of the argument for the role of cleaner-tech fuels and technologies is that they are not coal or nuclear and do not have similar environmental impacts. Sometimes the argument about a particular source is that it doesn't need baseload power to be effective. But, whatever they are, solutions must have political and societal support, make business and economic sense, have sound technical and scientific fundamentals, and coincide with sound long-term policy objectives. Natural gas (which has storage limits when it comes to electric generation) still suffers from a past history of price volatility and the potential for delivery interruptions—it may be plentiful soon, but inordinately increasing the amount of gas-fired generation has reliability implications and raises concerns about fuel diversity. Wind and solar are variable resources and usually generate electricity far from load centers. Small hydro also has variability issues; and, because no one is building new dams in the United States, the efficiencies created with large hydro are incremental. Geothermal can be generated only in the few places where the earth's heat is closest to the surface. Biomass, too, is generally smaller and far from load centers.

And all those solutions depend to one degree or another on the basic level of services provided by baseload plants. This story is about the role and necessity of baseload generation in the U.S. electrical system—and why not just any generating source will do.

Reserves

As Shakespeare's King Richard III discovered at Bosworth when he was willing to trade his kingdom for a horse, having backup can sometimes mean the difference between success and failure. Our electric system depends on physical laws, is one of the most complex and reliable systems in the world, and is a product of billions of dollars of investment and careful planning. (More than $1 trillion is planned between now and 2030, for upgrades and for expansion of the system with new technologies.) Those physical laws demand contingency planning: Every single watt of electricity used must be simultaneously generated, so the generating system must have the ability to put out more or less electricity instantly if a plant trips offline or load changes quickly or unexpectedly. The system needs plants in reserve that can do that.

Indeed, as a result of physical laws, the whole system must be resilient to deal with such risks as disruptions in the flow of power from plants or across transmission lines. The rules that specify these requirements are mandatory, not optional. Moreover, they are not arbitrary regulations. Promulgated by the North American Electric Reliability Corporation (NERC) and approved by the Federal Energy Regulatory Commission (FERC), they have been developed over years and informed by experiences with blackouts and system instability and through careful study.

From an engineering standpoint, system operators must adhere to complex rules for the system to remain stable. For example, the series of rules for loss-of-load probability (LOLP, the chance that demand will exceed load) requires that the main electric system have no more than a one-day-in-ten-year LOLP. "Single failure criteria" dictate that no single failure (or combination of probable failures) can cause the main system to fail.

Adherence to the NERC criteria over the years has led to one of the most reliable electric systems in the world. Failure to adhere to these rules has led to blackouts.

Required generation reserves are a function of several variables, but the main one is reliability of the plants operating at any given time. If a system with 10,000 megawatts (MW) of load had ten 1,000-MW plants that never failed or varied, then it would not need reserves. But plants do fail, and the system needs reserves to maintain a one-day-in ten-year LOLP and meet the single-failure criteria. The principle is simple: the more reliable the plants, the less the need for reserves; the less reliable the plants, the greater the need for reserves.

This has implications for renewables, which can be variable. Nuclear and coal-fired baseload plants, which run nearly continuously and whose output is controlled by the operator, fit the LOLP bill. They have the potential to trip off line, but because the system meets the single failure criteria, it can handle that possibility. With wind and solar plants, on the other hand, the output is variable and depends on the inputs: This type of plant, therefore, would require reserves for back-up power supply when the sun isn't shining and the wind isn't blowing during high demand periods.

There is some argument that renewables need no reserves—they are built solely for energy. But generating energy and counting as capacity are different things; and if wind and solar are built solely for energy, then they don't count as capacity. Under NERC's rules, the system must have capacity—the ability to generate whatever is needed whenever it is needed to meet peak loads. Still, it's also true that renewable facilities—if they're big enough, such as a wind farm in the strong and steady winds of North Dakota—can provide capacity, if they have purchased (or otherwise put in place) the necessary ancillary services, such as regulation. [See "The Storage Solution," page 60.] Traditional baseload units provide those services themselves.

The system also takes into account "joint probability"—that is, the probability that if one plant fails to generate, another will fail for the same reason. A drought can affect several hydro plants, for example, and system operators must consider that

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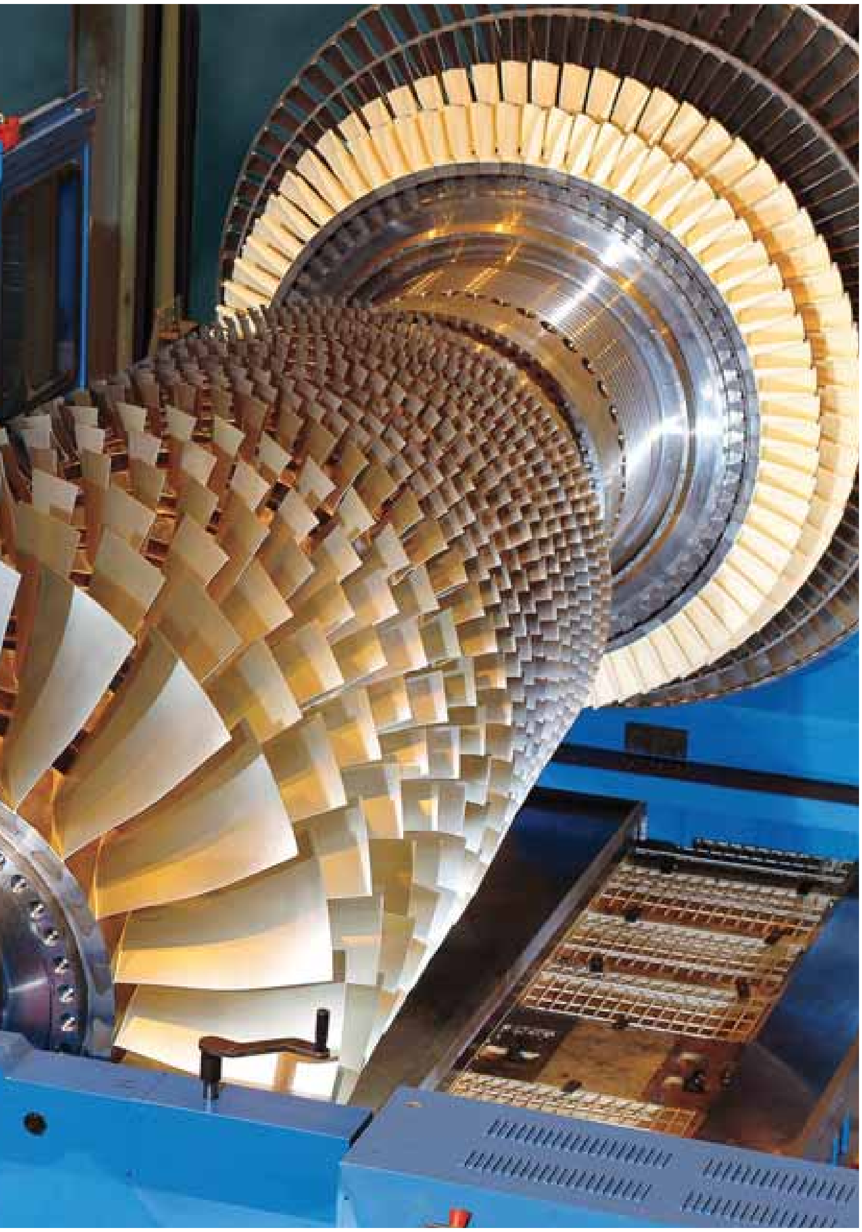

Courtesy: Siemens

Courtesy: Duke Energy

Small gas turbines can provide peak power but not inertia. Resources like solar can provide energy but typically not some ancillary services.

as they plan. Generally, coal, nuclear, natural gas, and hydro plants are independent from each other and have few joint probability issues. (However, if a hurricane, for example, were coming toward two nuclear plants not far from each other, they would be shut down to prevent the reactors from scramming, which would require a lengthy restart.) Generation that depends on variable sources like sun or wind have a high joint probability of outage because their energy inputs are a byproduct of nature and may be unavailable at the same time.

Separating wind and solar plants geographically makes joint probability quite low. Energy storage and forecasting technologies also help. Even so, this comes up against LOLP, requiring evidence that the probability of the wind quitting simultaneously in these areas is less than one-day-in-ten-years.

System Stability

It is hard to exaggerate the complexity involved in keeping the system balanced. It requires the coordination of thousands of power plants, billions of dollars of stability-specific investment, and the attention of thousands of engineers and system operators.

Those power plants generate power in a synchronous fashion, so that the amount of electricity generated across the system meets the amount used. Because the alternating current system in the United States sends current back and forth 60 times a second, the system must be set up to run on autopilot, so that it senses and compensates for interruptions. That task is continuous.

In delivering this system stability, baseload units are the anchors. For one thing, they provide generation inertia. In the first few microseconds after a plant drops off line, other baseload generators slow down as they pick up the loss. The inertia of big turbines—the energy represented by that decrease in momentum—is converted to electricity. This decrease in speed will continue until other units, usually smaller combustion gas turbines, pick up the load.

The last decade has seen a gradual decrease in generator inertia on the system. If this continues, we will need more inertia in the form of flywheels to maintain stability—inertia is the only source of energy that can pick up load quickly enough to prevent load shedding due to underfequency.

For all their size and speed, turbines are delicate machines: Their tolerances run in thousandths of an inch, though the tips of the low pressure turbine blades approach the speed of sound. The rotation speeds have a frequency of 60 hertz (HZ)—just slightly above or below, and there can be violent vibration, so the turbine will go offline in a case of under- or over-frequency. To prevent such a trip, the system uses underfrequency load shedding relays in substations, which cut off large amounts of load at once if the frequency falls. As the Western Blackout of 1996 showed, this is not always successful. Nor is it desirable—load-shedding is not an acceptable way to maintain system stability.

FREQUENCY WILL DROP MORE RAPIDLY ON A SYSTEM WITH LOW INERTIA THAN ON ONE WITH HIGH INERTIA. THIS IS A CONCERN FOR OTHER GENERATION SOURCES.

But frequency will drop more rapidly on a system with low inertia than on one with high inertia. This is a concern for other generation sources. If configured properly, wind can have a significant amount of inertia, but the distance from load is an issue. Hydro, due to the turbine set's large size, has more inertia per MW than just about anything.

Still, generator inertia can do only so much. It is a passive source of energy and is expended quickly. Thus, under NERC rules, there must be enough "spinning reserves" to quickly pick up lost generation before frequency can deteriorate. Critical to the spinning reserve calculation is the "ramp rate," the rate that the plant can increase its generation per minute. Coal plants generally have high inertia but a low ramp rate: It takes a relatively long time to pulverize coal, heat up the boiler, and so on. Nuclear is even worse. Thus to maintain ramp rate usually requires gas turbines.

Ramp rate requirements depend on, among other things, generator inertia and the largest amount of generation that could be lost. The more inertia, the less ramp rate is required, as the inertia will keep the system frequency up longer.

Transmission

No element in the electric system will be subject to greater change than our transmission system. It is true, though, that we cheat with coal, nuclear, and natural gas generation. We transmit the fuel hundreds or thousands of miles from its source to generation stations and then generate the electricity close to the load, avoiding most of the need

Less transmission line. Baseload plants tend to generate where the load is, not where the fuel is.

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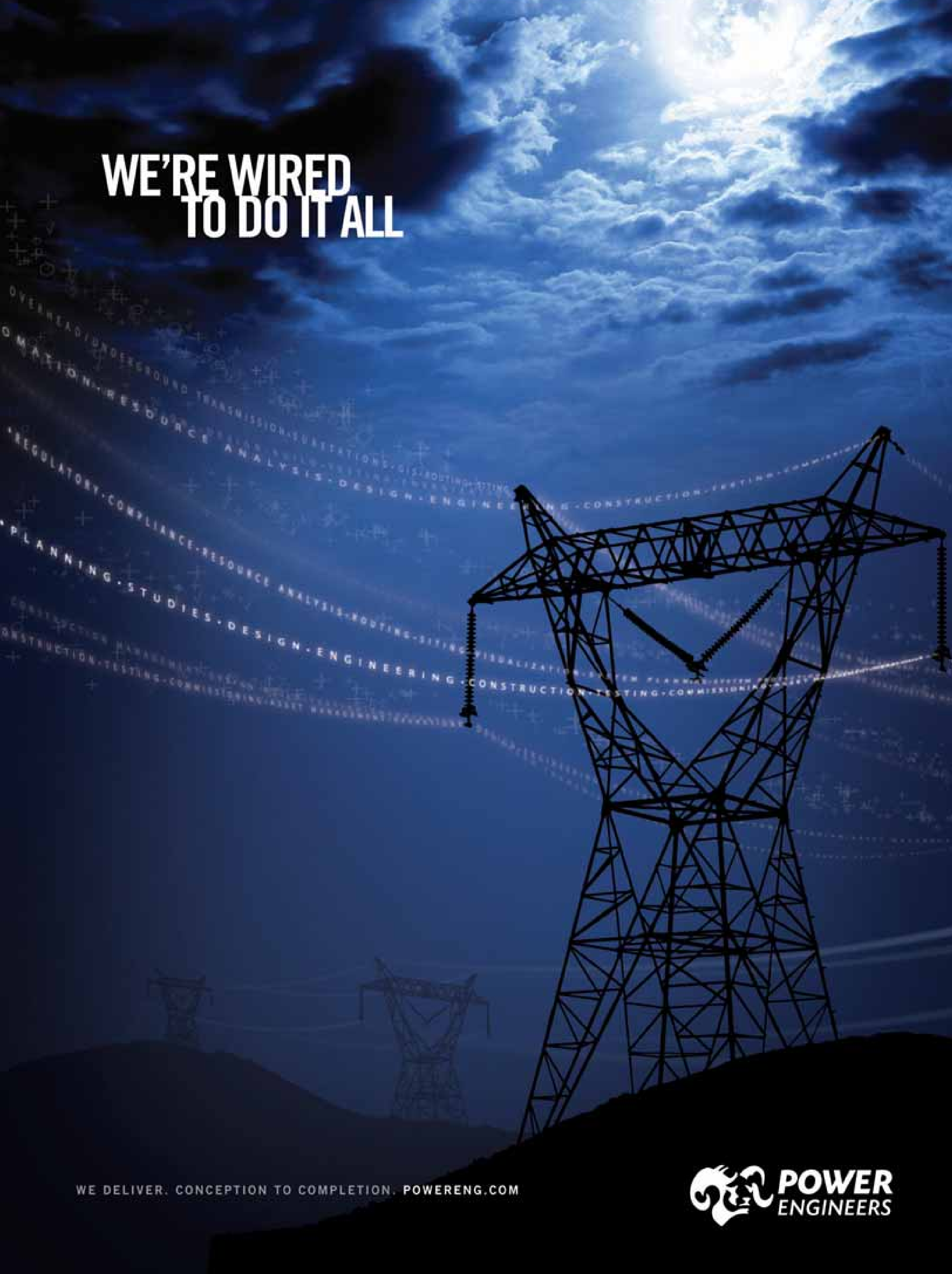
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for electric transmission. That is not possible with wind or solar. Of course, some renewables are close to the load, but the most abundant areas are usually not located near large cities. (Phoenix, Tucson, and Las Vegas are exceptions regarding solar, for example.) New coal, gas, and nuclear do not need as much transmission.

Today's transmission flows are by and large predictable, but that predictability lessens when we are generating with smaller, variable resources in one place today and another tomorrow, especially with their rapid ramp rates. The challenge of designing the transmission system to meet the single failure criteria will become greater; and the system stability in terms of ancillary services, transfer limits, and balancing will become more complex. Improvements in technology will help the challenges, certainly. Further, integrating this variability is one of the smart grid's main aims. But the task ahead is somewhat analogous to the difference between today's stability problem—where four 1,000-MW elephants pull your system in the same direction—and tomorrow's—where a thousand 4-MW cats pull in different directions.

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Reliability of Fuel Supply

Just as variable energy resources have fuel supply challenges, so does natural gas. We're not talking about gas reserves—with the capture of shale gas the United States probably has more than a 100-year supply—but gas is different from baseload coal and nuclear. For those generators, fuel is delivered far in advance. A nuclear plant on average has eight to nine months of fuel in the core; a coal plant usually has about 30 days of fuel onsite. Gas, on the other hand, is delivered "just in time." There is no onsite storage. The question is not how much gas there is—it's whether there is a sufficient amount of deliverable gas in, say, New England when it is 20 below zero for three days, the furnace in every gas-heated house is running at max, and electric space heaters are cranked up. The delivery system must meet the one-day-in-ten-year criteria.

Further, there is a growing problem of turbine operation with gas having different characteristics. A turbine will run on about any liquid or gas that burns—methane, jet fuel, and so on. But the turbine has to be tuned to run that fuel. If a turbine runs on methane and the natural gas pipeline, in a

Courtesy: GE / Duke Energy

Keeping the low-cost fuel option. Duke Energy's new IGCC plant at the Edwardsport (IN) power station.

crunch because of cold weather, starts withdrawal from a field containing imported liquefied natural gas with a large amount of ethane, the turbine can trip, leading to system instability. As we increasingly move to gas-fired generation, we must ensure that our turbine fleet can adjust to rapidly changing fuel or that the standards for pipeline quality are changed. From a reliability perspective, NERC probably should require that all gas turbines keep, on site, a two-week supply of something else that will burn in the turbine without harming it.

Solutions and Unintended Consequences

Again, global climate change is the largest single environmental problem we have faced, and we must take steps to reduce carbon dioxide (CO_2) emissions. At the same time, we must preserve our system's ability to deliver electricity when and where it is needed and therefore take system stability, reliability, and total cost into account as we pursue solutions. Our electric system not only concerns energy delivery; it also must furnish reliability and stability. Generators must provide those things—as baseload plants do—or acquire them.

AS WE STRIVE TO PRESERVE BASELOAD, WE ALSO NEED TO LOOK AT WASTE-ENERGY CONVERSION–THAT IS, USING THE OTHERWISE UNUSED HEAT PRODUCED BY GENERATION.

We need massive research into the best ways to reduce greenhouse emissions, achieve lowest cost, and maintain system reliability. The smart grid's ability to integrate variable energy resources is absolutely essential. We need to try many solutions, keeping in mind that generation, energy, capacity, and reliability are all different things, and each is necessary for our system to work.

We must work on clean coal technologies like those for carbon capture and storage (CCS)—we need to meet environmental criteria as we preserve the use of coal, which is low-cost. It comes down to a question of dispatch. The system is dispatched on a simple basis: Regardless of construction and other sunk costs, whichever plant has the lowest marginal cost dispatches next. Thus, all things being equal, hydro usually goes first, nuclear next, coal, and then gas units. With large amounts of renewable sources added to the mix, they dispatch first, as they have almost no marginal cost. On most systems, however, they don't displace coal—rather, they displace gas units, which have a higher operating cost. For one thing, this results in only about 40 percent as much CO_2 reduction as displacing coal. This will make gas units less attractive and harder to finance. (Low gas prices would alter this scenario.)

The implications of changes in the dispatch queues are profound—from increased O&M costs to lower rates of return than planned—and utilities must consider them.

If we institute high enough carbon tax or cap-and-trade scheme to induce significant switching from coal to gas, this will raise the cost of electricity enough to make CCS competitive. At that point, natural gas plants will not run when renewables are available and therefore will have low capacity factors. This will give them a lower rate of return and make them harder and more expensive to finance. Yet, with their ability to provide ancillary services like regulation, load following, etc., these are the very units that are critical to the stability of a system with large amounts of variable generation. This makes a good case for FERC adopting new pricing structures that recover the costs of providing ancillary services—this would allow the profitable operation of new gas units, running with lower capacity factors.

Unintended consequences or no, we need to pursue CCS. Aside from the benefits baseload power provides, we must establish world leadership. Even if the United States could switch entirely to cleaner generation, the rest of the world probably will not. Many countries will continue with pulverized coal plants without CCS. Unless we take leadership in developing the technology and lowering its cost, we may win the battle, but lose the war. In an age of globalization, we cannot unilaterally have a worldwide effect on emissions though regulation—it must be through technology.

As we strive to preserve baseload, we also need to look at waste-energy conversion—that is, using the otherwise unused heat produced by generation. Massive amounts of heat go to waste every day: A large power plant is usually no more than 50-percent efficient. Why don't we use that waste heat to heat or (using adsorptive chillers) cool buildings? Likewise, steel mills and other industrial facilities produce a lot of high-grade energy in their processes. Why don't we use it?

Another technology that will promote the integration of variable energy resources is demand response. DR is practically instantaneous—it is "hard wired" to cut load whenever instructed to do so. Clearly generator inertia and gas turbines are the first level of response in stabilizing the system, but DR gives it another level of robustness and allows a higher level of variable energy resources to be integrated.

The road to the future in electric power generation has never been straight, predictable, or easy. We need all those solutions to reach a low-carbon energy future. But we also need reliability and system stability. Baseload is the foundation. ◆