ENERGY

THE FUTURE WE DESERVE

# THE RISE OF THE PERSONAL POWER PLANT

## Agile power systems will let every home and business generate, store, and share electricity

By **Jean Kumagai**

**AT FIRST GLANCE, DOWNTOWN FORT COLLINS, COLORADO,** looks like a sweet anachronism. Beautifully preserved 19th-century buildings beckon from leafy streets. A restored trolley car ding-dings its way along Mountain Avenue. It's safe and spotless, vibrant and unrushed. • And yet this quaint district is ground zero for one of the most ambitious energy agendas of any municipality in the United States. Fort Collins, population 150 000, is trying to do something that no other community of its size has ever done: transform its downtown into a net-zero-energy district, meaning it will consume no more energy in a given year than it generates. And the city as a whole is aiming to reduce its carbon emissions by 80 percent by 2030, on the way to being carbon neutral by midcentury. To make all that happen, engineers there are preparing to



PHOTOGRAPH BY Adam Voorhes

aggressively deploy an array of advanced energy technologies, including combined-cycle gas turbines to replace aging coal-fired plants, as well as rooftop solar photovoltaics, community-supported solar gardens, wind turbines, thermal and electricity storage, microgrids, and energy-efficiency schemes.

It's an audacious plan. But for Fort Collins Utilities, the local electric company, the less daring options were unacceptable. Like utilities all over the world, it is grappling with the dissolution of the traditional regulated-monopoly model of electricity production, with its single, centralized decision maker. The costs of solar and wind electricity generation have fallen to the point that countless consumers in many countries now produce their own electricity, often (but not always) with the blessing of regulators and policymakers.

The question now is, how far do we want to go? In the coming decades, technology will let us radically decentralize the grid, enabling businesses, factories, campuses, and households to provide their own electricity for much of the day and most of the year. Solar energy, fuel cells, and wind turbines will all be cheaper than they are now. Power requirements will also be reduced, because heating, cooling, appliances, and lighting will all be more efficient. Advances in batteries and other forms of energy storage will make it easier to ride out the inevitable variations in solar and wind power and the reactive-power challenges that will arise. And smart grids, microgrids, and other technologies will knit these many microgenerators together in nimble networks that will let people sell excess energy and capacity while drawing from the main grid as needed.

Taken together, these advances will underpin a more sustainable energy future, in which nuclear and fossil fuels play a gradually declining role and the effects of pollution, greenhouse gases, and nuclear waste are reduced. But large-scale changes to the power system can take decades to put into place. So now is the time to envision what the grid should look like in 2030 and beyond.

Such a future won't happen—in Fort Collins or anywhere else—without overcoming significant challenges. These include not just technological but also political and regulatory issues. Today, every time a homeowner installs photovoltaic panels on the roof and begins spinning the household electricity meter backward, every time a plug-in hybrid owner decides to charge up the car batteries, and every time a new wind turbine starts to turn, it perturbs the grid. Though those individual perturbations may be slight, as they begin numbering in the hundreds of thousands or even millions, the strain on a grid not designed to handle them will become potentially disastrous.

**MORE BEER, FEWER WATTS:** Solar panels at the New Belgium Brewing Co. in Fort Collins, Colo., supply 3 percent of the plant's electricity. The brewery is participating in the city's long-term plans to create a net-zero-energy downtown district and to become carbon neutral by midcentury.

PREVIOUS PAGE: PROP STYLIST: ROBIN FINLAY; THIS PAGE: NEW BELGIUM BREWING (3)

THE ELECTRICITY INDUSTRY IS UNdergoing the same sort of fundamental change that has already transformed telecommunications and computing, says Clark Gellings, a fellow at the Electric Power Research Institute (EPRI), in Palo Alto, Calif. Recall the heyday of the telephone landline, when a monopoly provided reliable service, with few bells and no whistles. Today, a multitude of telecom providers offer more wired and wireless options and services than most people, frankly, care to contemplate. Computers, similarly, used to mean giant mainframes accessed via remote terminals. But when CPUs and memory became cheap enough and powerful enough, people could own their own computers, access and exchange information via the Internet, and leverage the power of distributed computation in the cloud.

Gellings envisions an analogue for electricity that he calls the ElectriNet: a highly interconnected and interactive network of power systems that also combines telecommunications, the Internet, and e-commerce. (Gellings first unveiled the then-heretical notion of electricity customers managing their own usage–a concept he called "demand-side load management"–in the December 1981 issue of *IEEE Spectrum*.) Such a network will allow traditional utilities to intelligently connect with individual households, service providers, and as yet unforeseen electricity players, fostering the billions of daily electricity "transactions" that will take place between generators and consumers. Smart appliances in the home will be able to respond to changes in electricity prices automatically by, for instance, turning themselves off or on as prices rise or fall. The ElectriNet will also allow for home security, data and communication services, and the like.

In addition, Gellings says, advanced sensors deployed throughout the network will let grid operators visualize the power system in real time, a key capability for detecting faults, physical attacks, and cyberattacks and for preventing or at least mitigating outages.

While distributed generation is already taking hold in many places, Gellings notes, "we have to move toward a truly integrated power system. That's a system that makes the best use of distributed and central resources–because central power generation is not going to go away, although it may change in shape and form." [For more on the undesirability

WHAT COULD POSSIBLY GO WRONG?

# The Slow Death of the Grid

## Too many off-grid personal power stations will undermine communal infrastructure

**The price of photovoltaic** cells continues to plummet while their efficiency continues to rise. Batteries and other energy-storage technologies are also getting better, prompting more people to unplug from the grid. If current trends continue, the result could be catastrophic, not just for the utilities but for anyone who wants access to affordable, stable electricity.

Here's why. "When you have mass defection from the grid, that means many people are overinvesting in individual, unnetworked assets to meet their own peak energy demands," says James Mandel, a manager at the Rocky Mountain Institute, in Boulder, Colo. "As a result, it leaves those least able to afford a personal power station—low-income customers, those who rent or have bad credit—to pick up the cost of the grid." And those homeowners and businesses going it alone might find operating and maintaining their own "utility in a box" expensive and time-consuming, he adds. Needless to say, as their revenues erode, grid operators will hardly be viable. "That's a future we'd rather not see," Mandel says.

In some places, though, that future is already here. In Hawaii, where electricity rates are typically more than 40 cents a kilowatt-hour, having your own solar PV array with battery storage now makes economic sense for anyone who can afford it. In a recent report, *The Economics of Grid Defection*, the Rocky Mountain Institute predicted when that "grid parity" tipping point would occur in five U.S. regions. In Los Angeles and in New York's Westchester County, for example, it could happen as early as 2020. Advances in other local generation options, such as combined heat and power systems that run off hydrogen fuel cells, could encourage even more people to leave the grid.

The report was intended as a wake-up call, Mandel says. "When grid defection becomes viable, it's not a 'could happen,' it's a 'will happen.'" So six years or maybe a little longer, he says, "is how long we have to figure out a better model."

The preferred future, according to the report's authors and many other power experts, is a grid with even greater connectivity and smarts. The worst-case scenario, says Clark Gellings, a fellow at the Electric Power Research Institute, is that "the smart grid isn't really smart. It's dumb, and we don't get the interconnectivity right." In that bleak future, customers who once had access to relatively cheap and reliable service will face enormous price swings and frequent, chronic blackouts. And without a robust, sustainable grid, the other swell futures envisioned elsewhere in this issue—self-driving cars, household robots, thought-detecting wearable computers, and so on—won't come to pass either.

"My preferred vision of the future isn't at all inevitable," Gellings admits. "That's why I'm out there every day, traveling around the country, meeting with regulators and utilities, trying to get the message across." *—J.K.*

ILLUSTRATION BY MCKIBILLO

of grid defection, see the sidebar, "The Slow Death of the Grid."]

A highly intelligent and agile network that can handle the myriad transactions taking place among hundreds of thousands or even millions of individual energy producers and consumers isn't just desirable, say experts. It has to happen, because the alternative would be grim.

Just ask the Germans. Generous subsidies, called feed-in tariffs, for renewable energy resulted in the country adding 30 gigawatts of solar and 30 gigawatts of wind power in just a few years. On a bright breezy day at noon, renewables can account for more than half of Germany's generated electricity.

"That sounds like a good thing, but to the utility, it looked like a huge negative load," notes Benjamin Kroposki, director of energy systems integration at the National Renewable Energy Laboratory in Golden, Colo. When a large amount of renewable power is being generated, the output of conventional central power plants is correspondingly reduced to keep the system balanced. But if a local outage or a voltage spike or some other grid disturbance occurs, protective circuitry quickly shuts down the photovoltaics' inverters. (Inverters are semiconductor-based systems that convert the direct current from the solar cells to alternating current.) And that in turn can lead to cascading systemwide instabilities.

"If you lose 30 gigawatts in just 10 cycles"–two-tenths of a second, that is–"you can't ramp up conventional generators quickly enough to compensate," Kroposki notes. So the Germans had to spend the equivalent of hundreds of millions of dollars on smarter inverters and communication links that would allow the PV arrays to automatically ride through any disturbances rather than simply shut down.

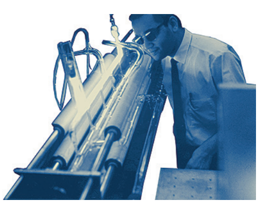
Customers are paying dearly for those upgrades: Electricity rates in Germany have doubled since 2002, to about 40 U.S. cents per kilowatt-hour. That's more than four times the price of electricity in Illinois. Many other countries are now learning from these experiences, Kroposki adds, "to make sure that solar and wind systems integrate with the grid in ways that help overall system stability."

A SIZABLE JAPANESE EXPERIMENT is taking such an integrated approach. At a site 30 minutes by train from central Tokyo, a real estate developer is turning an old golf course into a planned smart city called Kashiwanoha. Energy, water, and other public services for an eventual population of 26 000 are being intelligently managed at every scale, from individual households to businesses and factories to citywide networks.

The smart-city concept has been kicking around for a while. But it didn't really take hold in Japan until the Fukushima disaster in March 2011, says Akihiko Tobe, general manager of Hitachi's smart-city project division, which is furnishing the energy management systems for Kashiwanoha. "The earthquake changed everything," Tobe says. "Many cities suffered great damage, with power breakdowns and

**WATTS WHERE NONE EXISTED BEFORE:** A reimagined energy future with more distributed generation, storage, and microgrids isn't just for people in wealthy countries. It will also include those who have no access to electricity—that's nearly 1.3 billion people right now. Indeed, it's already happening. SharedSolar, a project started by Columbia University's Vijay Modi and some of his students, is rolling out small photovoltaic arrays connected by a microgrid in villages across sub-Saharan Africa. Households and businesses prepay for their electricity, in much the same way they might prepay for cellphone service.

PHOTO: SHAREDSOLAR



TIME CAPSULE: 1964

## CARBON DIOXIDE LASER

**After finishing his Ph.D. at Stanford, C. Kumar N. Patel joined Bell Labs and led the team that in 1964 developed the most powerful continuously operating laser. The carbon dioxide laser is now used for cutting diamonds, analyzing the upper atmosphere, and removing tumors, among other things.**

PHOTO-ILLUSTRATION BY Gluekit

water shutdowns. In tall buildings, elderly people were trapped on high floors because the elevators stopped working."

And so Kashiwanoha's electricity system is designed to provide uninterrupted service to critical systems like elevators, water pumps, and hospitals in the event of an emergency. To do that, it relies on several battery storage sites as well as a microgrid, which facilitates the sharing of electricity and can operate in isolation of the main grid. A command center on the second floor of a hotel and apartment building oversees the microgrid and tracks exactly where electricity is being consumed and generated. During normal operation, customers are also encouraged to track their own energy usage through touch-screen monitors in their homes and businesses. Those who do an especially good job of reducing their consumption are awarded "eco points," which they can exchange for goods and services at the local LaLaPort shopping center.

> **"A good electricity future will depend on every new technology you can think of"**

Eventually, says Tobe, more home automation will be added, like sensors that automatically turn off lights when the curtains are opened. Health-care monitoring will also be offered, to track things like how much exercise you get and how many calories you eat. People who move to Kashiwanoha realize that the city represents a break with the past, says Tobe. "Their mind-set is that they're establishing a new culture, and they're highly motivated to participate in making life better."

ASSUMING THAT FORWARD-LOOKING cities like Fort Collins and Kashiwanoha reach their energy goals, can that success be replicated? "A good electricity future will depend on every new technology you can think of," says EPRI's Gellings. "Energy storage, device efficiency, better ways to mine coal and extract natural gas, grid sensors, more advanced generation." Should any one of these technologies not progress in the way that experts now assume they will, it could throw a wrench in the works, he says. Regulators and policymakers will also need to be convinced to make the hefty investments in infrastructure that a smarter integrated grid will require.

Even if all these changes come to pass, the grid in 2064 will still look a lot like today's grid in some key ways. Big coal plants, for instance, will remain a large part of the energy mix. According to the U.S. Energy Information Administration's *International Energy Outlook 2013*, the United States, Australia, and many other countries will retire their aging coal plants, but other countries will continue to build new ones. China, already the world's leading coal user, will add about 530 gigawatts of coal-fired power capacity by 2040, the report projects. And so coal's share of electricity generation worldwide in 2040 will likely be just a few percentage points below what it was in 2010.

And once those new plants come on line, they'll be hard to budge. "This is a very inertial field," says Vaclav Smil, who's studied the slow pace of change in the power industry. "A single power plant costs like a billion dollars to build. Once you put it in place, you don't want to tear it out and start again. So innovation will happen mainly at the margins."

Innovation at the margins could still lead to profound changes in the future grid, if cities like Fort Collins and Kashiwanoha get it right. Fifty years from now, says Steve Catanach, manager of light and power at Fort Collins Utilities, the two coal-fired plants from which the city draws 80 percent of its electricity will no longer be active. Taking their place will be new combined-cycle gas turbines but also a larger share of distributed generation. These days, the utility is actively encouraging investments in wind and solar through a new feed-in tariff, which will let customers sell their electricity back to the grid at a guaranteed rate. Greater use of demand-response mechanisms will allow customers to curtail their usage during times of peak demand. And when energy storage becomes affordable, Catanach adds, "we'll use that to balance the variability of the renewables."

While some industry experts are wringing their hands over the looming "death spiral" for today's utilities, Catanach manages to sound optimistic about what's to come. "Fort Collins is a great place to live, and the lights are always on," he says. He's pretty sure that 50 years from now, people will still be able to say the same thing. ■

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