ENVIRONMENT

Our future rides on our ability to integrate

ENERGY + WATER + FOOD

A Puzzle for the Planet

By Michael E. Webber

Photograph by Dan Saelinger

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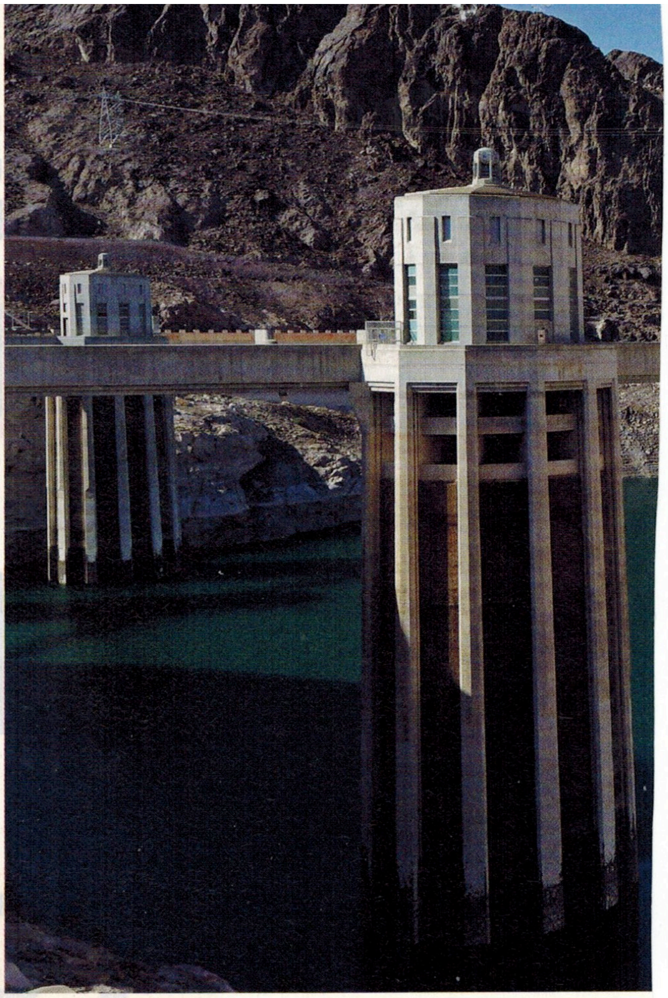

IN JULY 2012 THREE OF INDIA'S REGIONAL electric grids failed, triggering the largest blackout on earth. More than 620 million people—9 percent of the world's population—were left powerless. The cause: the strain of food production from a lack of water. Because of major drought, farmers plugged in more and more electric pumps to draw water from deeper and deeper belowground for irrigation. Those pumps, working furiously under the hot sun, increased the demand on power plants. At the same time, low water levels meant hydroelectric dams were generating less electricity than normal.

Making matters worse, runoff from those irrigated farms during floods earlier in the year left piles of silt right behind the dams, reducing the water capacity in the dam reservoirs. Suddenly, a population larger than all of Europe and twice as large as that of the U.S. was plunged into darkness.

California is facing a surprisingly similar confluence of energy, water and food troubles. Reduced snowpack, record-low rainfall and ongoing development in the Colorado River basin have reduced the river water in central California by a third. The state produces half of the country's fruits, nuts and vegetables and almost a quarter of its milk, and farmers are pumping groundwater like mad; last summer some areas pumped twice as much water for irrigation as they did the previous year. The 400-mile-long Central Valley is literally sinking as groundwater is pulled up from below. Just when more power is needed, Southern California Edison shut down two big nuclear reactors for a lack of cooling water. San Diego's plan to build a desalination plant along the coast was challenged by activists who opposed the facility on the grounds that it would consume too much energy.

Energy, water and food are the world's three most critical resources. Although this fact is widely acknowledged in policy circles, the interdependence of these resources on one another is significantly underappreciated. Strains on any one can cripple the others. This situation has made our society more fragile than we imagine, and we are not prepared for the potential disaster that is waiting for us.

Yet we are making once-in-a-generation decisions about power plants, water infrastructure and farmland that will last for many decades, locking us into a vulnerable system. Meeting the world's energy needs alone will require $48 trillion in investment between now and 2035, according to a 2014 International Energy Agency report, and the agency's executive director said there is a real risk "that investments are misdirected" because impacts are not being properly assessed.

IN BRIEF

The world is trying to improve energy, water and food supplies individually, but the challenges need to be solved in one integrated manner. That approach will also benefit the environment, poverty, population growth and disease. **Reducing wasted food** can conserve energy and water. Indoor farms can use city wastewater to grow crops and power the buildings in which they are housed. Algae production next to power plants can turn wastewater and carbon emissions into food or biofuel. Wind turbines in the desert can convert brackish water into freshwater. A smart grid for water delivery can save water and energy. **Energy, water and food** planners and policy makers have to stop working in isolation and devise integrated policy and infrastructure solutions.

PAGE 62: PROP STYLING BY DOMINIQUE BAYNES; THIS PAGE: ETHAN MILLER *Getty Images*

LAKE MEAD in Arizona and Nevada hit a record low in July 2014, threatening to limit drinking water for Las Vegas, irrigation for farms and power from the Hoover Dam.

An integrated approach to solving these enormous issues is urgently needed rather than an attempt to solve each problem apart from the others. A vast number of the planet's population centers are hit with drought, energy systems are bumping up against environmental constraints and rising costs, and the food system is struggling to keep up with rapidly growing demand. And the nexus of food, water and energy is a backdrop to much of the most troubled parts of the world. Riots and revolutions in Libya and Syria were provoked by drought or high food prices, toppling governments. We need to solve the interconnected conundrum to create a more integrated and resilient society, but where do we start?

CASCADING RISKS OR REWARDS

THE LATE NOBEL LAUREATE Richard E. Smalley of Rice University gave a hint at where to begin in his 2003 lecture highlighting the "Top Ten Problems of Humanity for the Next 50 Years." His list was organized in descending order of importance: energy, water, food, environment, poverty, terrorism and war, disease, education, democracy and population. Energy, water and food were at the top because solving them would combat problems lower down, in cascading fashion. Developing plentiful sources of clean, reliable, affordable energy, for example, enables an abundance of clean water. Having an abundance of clean water and energy (to make fertilizer and to power tractors) enables food production. And so on.

As brilliant as Smalley's list was, it missed two important nuances. First, energy, water and food are interconnected. And second, although an abundance of one enables an abundance of the others, a shortage of one can create a shortage of the others.

With infinite energy, we have all the water we need because we can desalt the oceans, dig very deep wells and move water across continents. With infinite water, we have all the energy we need because we can build widespread hydroelectric plants or irrigate unlimited energy crops. With infinite energy and water we can make the deserts bloom and build highly productive indoor farms that produce food year-round.

We do not live in a world with infinite resources, of course. We live in a world of constraints. The likelihood that these constraints will lead to cascading failures grows as pressure rises from population growth, longer life spans and increasing consumption.

For example, Lake Mead outside Las Vegas, fed by the Colorado River, is now at its lowest level in history. The city draws drinking water from what amounts to two big straws that dip into the lake. If the level keeps dropping, it may sink lower than those straws: large farming communities downstream could be left dry, and the huge hydroelectric turbines inside the Hoover Dam on the lake would provide less power or might stop altogether. Las Vegas's solution is to spend nearly $1 billion on a third straw that will come up into the lake from underneath. It might not do much good. Scientists at the Scripps Institution of Oceanography in La Jolla, Calif., have found that Lake Mead could dry up by 2021 if the climate changes as expected and cities and farms that depend on the Colorado River do not curtail their withdrawals.

In Uruguay, politicians must confront tough decisions about how to use the water in their reservoirs. In 2008 the Uruguay River behind the Salto Grande Dam dropped to very low levels. The dam has almost the same electricity-generating capacity as the Hoover Dam, but only three of the 14 turbines were spinning because local people wanted to store the water for farming or municipal use. The citizens along the river and their political leaders were forced to choose whether they wanted electricity, food or drinking water. Constraints in one sector triggered constraints in the others. Although that threat might have temporarily eased for Uruguay, it repeats itself in other parts of the world. In like manner, certain communities in drought-stricken Texas and New Mexico have recently prohibited or restricted water for use in fracking for oil and gas, saving it for farming.

About 80 percent of the water we consume is for agriculture—our food. Nearly 13 percent of energy production is used to fetch, clean, deliver, heat, chill and dispose of our water. Fertilizers made from natural gas, pesticides made from petroleum, and diesel fuel to run tractors and harvesters drive up the amount of energy it takes to produce food. Food factories requiring power-hungry refrigeration produce goods wrapped in plastic made from petrochemicals, and it takes still more energy to get groceries from the store and cook them at home. The nexus is a big mess, and the entire system is vulnerable to a perturbation in any part.

PASSENGERS in Kolkata, India, were stranded after a huge 2012 blackout, triggered by too many pumps straining to water farms during drought.

BIKAS DAS AP Photo

TECHNICAL SOLUTIONS

IT WOULD BE FOLLY to build more power plants and water delivery and treatment facilities with the same old designs, to grow crops using the same outdated methods, and to extract more oil and gas without realizing that these pursuits impinge on one another. Thankfully, it is possible to integrate all three activities in ways that are sustainable.

The most obvious measure is to reduce waste. In the U.S., 25 percent or more of our food goes into the dump. Because we pour so much energy and water into producing food, reducing the proportion of waste can spare several resources at once. That might mean something as simple as serving smaller portions and eating less meat, which is four times more energy-intensive than grains. We can also put discarded food and agricultural waste such as manure into anaerobic digesters that turn it into natural gas. These metal spheres look like shiny bubbles. Microbes inside break down the organic matter, producing methane in the process. If we implement this technology widely—at homes, grocery stores and central locations such as farms—that would create new energy and revenue streams while reducing the energy and water that are needed to process the refuse.

Wastewater is another by-product we could turn into a resource. In California, San Diego and Santa Clara are using treated wastewater to irrigate land. The water is even clean enough to drink, which could bolster municipal water supplies if state regulators would allow it.

Urban farm proponents such as Dickson Despommier of Columbia University have designed "vertical farms" that would be housed inside glass skyscrapers. People in New York City, for example, produce a billion gallons of wastewater a day, and the city spends enormous sums to clean it enough to dump into the Hudson River. This cleansed water could instead irrigate crops inside a vertical farm, generating food while reducing the farm's demand for freshwater. Solids extracted from liquid waste are typically burned, but instead they could be incinerated to produce electricity for the big building, reducing its energy demand. And because fresh food would be grown right where many consumers live and work, less transportation would be needed to truck food in, potentially saving energy and carbon dioxide emissions.

Start-up companies are trying to use wastewater and CO_2 from power plants to grow algae right next door. The algae eat the gas and water, and workers harvest the plants for animal feed and biofuel, all while tackling the fourth priority on Smalley's list—improving the environment—by removing compounds from the water and CO_2 from the atmosphere.

We could harness the same carbon dioxide to create energy. My colleagues at the University of Texas at Austin have designed a system in which waste CO_2 from power plants is in-

SCIENTIFIC AMERICAN ONLINE Video about resource-efficient aquaculture can be seen at ScientificAmerican.com/feb2015/webber

jected into large brine deposits deep belowground. The CO_2 stays submerged, eliminating it from the atmosphere, and pushes out hot methane, which comes to the surface, where it can be sold for energy. The heat can also be tapped by industry.

Smart conservation is another way to spare different resources simultaneously. We use more water through our light switches and electrical outlets than our faucets and showerheads because so much water is needed to cool power plants that are out of sight and out of mind. We also use more energy to heat, treat and pump our water than we use for lighting. Turning off the lights and appliances saves vast amounts of water, and turning off the water saves large amounts of energy.

We can also rethink how to better use energy and water to grow food in unlikely places. In parts of the desert Southwest, brackish groundwater is abundant at shallow depths. Wind and solar energy are also plentiful. These energy sources present challenges to utilities because the sun does not shine at night and the wind blows intermittently. But that schedule is fine for desalting water because clean water is easy to store for use later. Desalination of seawater is energy-intensive, but brackish groundwater is not nearly as salty. Our research at U.T. Austin indicates that intermittent wind power is more economically valuable when it is used to make clean water from brackish groundwater than when it is used to make electricity. And of course, the treated water can then irrigate crops. This is the nexus working in our favor.

The same thinking can improve hydraulic fracturing for oil and gas. One unfortunate side effect is that waste gas, mostly methane, coming up the well is flared—burned off into the air. The flaring is so voluminous that it can be seen at night from space. The wells also produce a lot of dirty water—millions of gallons of freshwater injected into wells for fracking come back out laden with salts and chemicals. If operators are smart, they can use the methane to power distillers or other heat-based machines to clean the water, making it reusable on-site, which spares freshwater while avoiding the wasted energy and emissions of a flare.

We can also be smarter about how we deliver water to homes and businesses. Sensors embedded in smart grids help to make electricity distribution more efficient. But our water system is a lot dumber than our electricity system. Outdated, century-old meters often fail to accurately record water use, and experts say that antiquated pipes leak 10 to 40 percent of the treated water that flows through them. Embedding wireless data sensors in the water delivery system would give utilities more tools to reduce the leaks—and lost revenues. Smart water would also help consumers manage their consumption.

We can do smart food, too. One reason so much food is wasted is because grocery stores, restaurants and consumers rely on expiration dates, a crude estimate of whether food has spoiled. Food is not sold or consumed past the expiration date even though it may still be fine if its temperature and condition have been well managed. Using sensors to assess food directly would be smarter. For example, we could use special inks on food packaging that change color if they are exposed to the wrong temperature or if undesirable microbes begin to grow in the food, indicating spoilage. We can install sensors along the supply chain to measure trace gases that are released by rotting fruits and vegetables. Those same sensors can lead to tighter refrigeration controls that minimize losses.

NEW POLICY THINKING

ALTHOUGH MANY TECHNICAL SOLUTIONS can improve the energy-water-food nexus, we often do not exploit them because ideologically and politically, the U.S. has not fully grasped the interrelatedness of these resources. Policy makers, business owners and engineers typically work in isolated fashion on one issue or another.

Sadly, we compound the problems with policy, oversight and funding decisions made by separate agencies. Energy planners assume they will have the water they need. Water planners assume they will have the energy they need. Food planners recognize the risks of drought, but their reaction is to pump harder and drill deeper for water. The most important innovation we need is holistic thinking about all of our resources.

That kind of thinking can lead to smarter policy decisions. For example, policies can fund research into energy technologies that are water-lean, water technologies that are energy-lean, and food production, storage and monitoring techniques that prevent losses while reducing energy and water demands. Setting cross-resource efficiency standards can kill two birds with one stone. Building codes can also be a powerful tool for reducing waste and improving performance. Permitting for new energy sites should require water-footprint assessments, and vice versa. And policy makers can set up revolving loan funds, direct capital investments or tax benefits for institutions that integrate these kinds of technical solutions.

One encouraging sign was a declaration made by 300 delegates from 33 countries at the Nexus 2014: Water, Food, Climate and Energy Conference in Chapel Hill, N.C. The declaration, written not just by political representatives but also by attendees from the World Bank and the World Business Council for Sustainable Development, stated that "the world is a single complex system" and that "solutions and policy interventions should be sought that are beneficial for the system as a whole."

As Smalley pointed out, energy can be the driver. We have to think about using our energy sector to solve multiple challenges simultaneously. Policies that are monomaniacal about lowering atmospheric CO_2 levels, for example, might push us toward low-carbon electricity choices that are very water-intensive, such as nuclear power plants or coal plants with carbon capture.

Personal responsibility plays a role, too. Demand for fresh salads that land on our winter plates from 5,000 miles away creates a far-flung, energy-hungry food distribution system. In general, our personal choices for more of everything just push our resources to the edge. The energy-water-food nexus is the most vexing problem to face our planet. To quote the late George Mitchell, father of modern hydraulic fracturing and a sustainability advocate: "If we can't solve the problem for seven billion people, how will we do so for nine billion people?" SA

MORE TO EXPLORE

Liberation Power: What Do Women Need? Better Energy. Sheril R. Kirshenbaum and Michael E. Webber in Slate. Published online November 4, 2013.

The Ocean under Our Feet. Michael E. Webber in *Mechanical Engineering*, page 16; January 2014.

FROM OUR ARCHIVES

The One-Stop Carbon Solution. Steven L. Bryant; November 2013.

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