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Plugging Into the Sun

Sunlight bathes us in far more energy than we could ever need—if we could just catch enough.

By George Johnson

Early on a clear November morning in the Mojave Desert, the sun is barely touching the peaks of the McCullough Range with a cool pink glow. Behind them, a full moon is sinking over the gigawatt glare of Las Vegas. Nevada Solar One is sleeping. But the day's work is about to begin.

It is hard to imagine that a power plant could be so beautiful: 250 acres of gently curved mirrors lined up in long troughs like canals of light. Parked facing the ground overnight, they are starting to awaken—more than 182,000 of them—and follow the sun.

"Looks like this will be a 700-degree day," says one of the operators in the control room. His job is to monitor the rows of parabolically shaped mirrors as they concentrate sunlight on long steel pipes filled with circulating oil, heating it as high as 750 degrees Fahrenheit. From the mirror field, the blistering liquid pours into giant radiators that extract the heat and boil water into steam. The steam drives a turbine and dynamo, pushing as much as 64 megawatts onto the grid—enough to electrify 14,000 households or a few Las Vegas casinos. "Once the system makes steam, it's very traditional—industry-standard stuff," says plant manager Robert Cable, pointing toward a gas-fired power plant on the other side of Eldorado Valley Drive. "We get the same tools and the same parts as the place across the street."

When Nevada Solar One came on line in 2007, it was the first large solar plant to be built in the United States in more than 17 years. During that time, solar technology blossomed elsewhere. Nevada Solar One belongs to Acciona, a Spanish company that generates electricity here and sells it to NV Energy, the regional utility. The mirrors were made in Germany.

Putting on hard hats and dark glasses, Cable and I get into his pickup and drive slowly past row after row of mirrors. Men with a water truck are hosing down some. "Any kind of dust affects them," Cable says. At the far edge of the mirror field, we stop and step out of the truck for a closer look. To show how sturdy the glass is, Cable bangs it like a drum. Above his head, at the focal point of the parabola, the pipe carrying the oil is coated with black ceramic to soak up the light, and it's encased in an airless glass cylinder for insulation. On a clear summer day with the sun directly overhead, Nevada Solar One can convert about 21 percent of the sun's rays into electricity. Gas plants are more efficient, but this fuel is free. And it doesn't emit planet-warming carbon dioxide.

About every 30 seconds there is a soft buzz as a motor moves the mirrors a little higher; by midday they will be looking straight up. It's so quiet out here one can hardly fathom how much work is being done: Each of the 760 arrays of mirrors can produce about 84,000 watts—almost 113 horsepower. By 8 a.m. the oil coursing through the pipes has reached operating temperature. A white plume is spewing from a cooling stack. Half an hour later, the sound of the turbine inside the generating station has reached a high-pitched scream. Nevada Solar One is ready to go on line.

With a new administration in Washington promising to take on global warming and loosen the grip of foreign oil, solar energy finally may be coming of age. Last year oil prices spiked to more than $140 a barrel before plunging along with the economy—a reminder of the dangers of tying the future to something as unpredictable as oil. Washington, confronting the worst recession since the 1930s, is underwriting massive projects to overhaul the country's infrastructure, including its energy supply. In his inaugural address President Barack Obama promised to "harness the sun and the winds and the soil to fuel our cars and run our factories." His 2010 budget called for doubling the country's renewable energy capacity in three years. Wind turbines and biofuels will be important contributors. But no form of energy is more abundant than the sun.

"If we talk about geothermal or wind, all these other sources of renewable energy are limited in their quantity," Eicke Weber, director of the Fraunhofer Institute for Solar Energy Systems, in Freiburg, Germany, told me last fall. "The total power needs of the humans on Earth is approximately 16 terawatts," he said. (A terawatt is a trillion watts.) "In the year 2020 it is expected to grow to 20 terawatts. The sunshine on the solid part of the Earth is 120,000 terawatts. From this perspective, energy from the sun is virtually unlimited."

There are two main ways to harness it. The first is to produce steam, either with parabolic troughs like the ones in Nevada or with a field of flat, computer-guided mirrors, called heliostats, that focus sunlight on a receiver on top of an enormous "power tower." The second way is to convert sunlight directly into electricity with photovoltaic (PV) panels made of semiconductors such as silicon.

Each approach has its advantages. Right now steam generation, also known as concentrating solar or solar thermal, is more efficient than photovoltaic—a greater percentage of incoming sunlight is converted into electricity. But it requires acres of land and long transmission lines to bring the power to market. Photovoltaic panels can be placed on rooftops at the point where the power is needed. Both energy sources share an obvious drawback: They fade when it's cloudy and disappear at night. But engineers are already developing systems for storing the energy for use in the darker hours.

The optimists say that with steady, incremental improvements—no huge breakthroughs are required—and with substantial government support, solar power could become as economical and efficient as fossil fuels. The pessimists say they've heard all this before—30 years ago, during the presidency of Jimmy Carter. That too was a period of national crisis, triggered by the Arab oil embargo of 1973. Addressing the nation in his cardigan sweater, President Carter called for a new national energy policy with solar energy playing a large part. In 1979 the Islamic revolution in Iran sent oil prices soaring again. American drivers lined up for gasoline, their radios blaring songs like "Bomb Iran," by Vince Vance and the Valiants (sung to the tune of the Beach Boys' "Barbara Ann"). Carter, true to his word, put solar water heaters on the White House roof.

During the next few years, two large fields of parabolic troughs, SEGS I and II (for Solar Electric Generating Station) were installed about 160 miles southwest of Las Vegas, near Daggett, California. They were followed by seven more plants nearby, at Kramer Junction and beside waterless Harper Lake. The plants are still operating—about a million mirrors in all on some 1,600 acres with a combined power of 354 megawatts. From afar they look like mirages.

The momentum didn't last. As the economy adjusted to the Iranian oil shock, fuel prices fell. With the sense of urgency reduced, along with the research dollars, solar remained a minor factor in the energy equation. The SEGS plants were still being built when President Ronald Reagan took the solar water heaters off the White House roof. The first solar revolution fizzled.

Two decades later, a new solar revolution may be ready to begin.

Another legacy of the Carter era, the National Renewable Energy Laboratory (NREL) in Golden, Colorado—the government's primary research center for solar, wind, hydrogen, and other alternative fuels—is bracing for a resurgence. When I visited last fall, a new research campus and headquarters were under construction against the side of a mountain outside Golden. Five acres of photovoltaic panels on top of the mesa will feed the labs and offices below. That may be just the beginning. Once treated by the government as something of a stepchild, NREL is benefiting from the extra money the Obama Administration is devoting to renewable energy. "Right now solar is such a small fraction of U.S. electricity production that it's measured in tenths of a percent," said Robert Hawsey, an associate director of the lab. "But that's expected to grow. Ten to 20 percent of the nation's peak electricity demand could be provided by solar energy by 2030."

But not without government help. Nevada Solar One would never have been built if the state had not set a deadline requiring utilities to generate 20 percent of their power from renewable sources by 2015. (More than two dozen states now have "renewable-portfolio standards," and earlier this year Congress was debating a federal one.) During peak demand—a hot afternoon in Las Vegas, when production costs are highest—the solar plant's electricity is almost as cheap as that of its gas-fired neighbor. But that's only because a 30 percent federal tax credit helped offset its construction costs.

Aiming to bring down costs and reduce the need for incentives, NREL's engineers are studying mirrors made from lightweight polymers instead of glass and receiving tubes that will absorb more sunlight and lose less heat. They're also working on solar power's biggest problem: how to store some of the heat produced during daylight hours for release later on. "In the Southwest particularly, peak loads are in the daytime, but they don't end when the sun goes down," said Mark Mehos, an NREL program manager. People come home from work, turn on lights and air conditioners. Before long they may be plugging in electric cars.

Last year the first commercial solar plant with heat storage opened near Guadix, Spain, east of Granada. During the day, sunlight from a mirror field is used to heat molten salt. In the evening, as the salt cools, it gives back heat to make more steam. In Arizona the Solana Generating Station will also use molten salt for storage. When it goes on line in 2012, three square miles of parabolic troughs will produce 280 megawatts for Phoenix and Tucson. Solana is being built by a Spanish company, Abengoa Solar—an indication of just how far, in the development of this technology, the United States has fallen behind.

Back in the 1980s, an engineer named Roland Hulstrom calculated that if photovoltaic panels—the other big solar technology—covered just three-tenths of a percent of the United States, a 100-by-100-mile square, they could electrify the entire country.

People thought he wanted to pave the Mojave with silicon. "The environmentalists got up in arms and said, You can't just go out and cover a hundred miles square," Hulstrom said recently as he sat in his office at NREL. But that's not what he meant. "You can cover parking lots with photovoltaic. You can put it on house roofs."

Twenty years later, PV panels still contribute only a tiny amount to the nation's electricity supply. But on rooftops in California, Nevada, and other states with good sunshine and tax incentives, they're a sight almost as familiar as air conditioners—and though not yet as developed as solar thermal, they may have a brighter future.

Right now the panels are expensive, and they provide an efficiency of only about 10 to 20 percent, compared with the 24 percent of parabolic troughs. History more than physics is to blame. After the solar bust in the mid-1980s, many of the best engineers migrated to the computing industry, which uses the same raw material—silicon and other semiconductors. Following what is called Moore's law, microprocessors doubled in capability every couple of years, while solar languished. Now some of the engineering talent is moving back to solar.

Researchers at NREL are exploiting the fact that different semiconductors capture different colors from a beam of sunlight. By layering compounds called gallium indium phosphide and gallium indium arsenide and using a lens to concentrate sunlight, they built a PV cell last year that is 40.8 percent efficient (a world record, since broken). But it's far from ready for mass production. "The technology is incredibly sophisticated," said Ray Stults, an associate director of the laboratory. "We can make it right now for $10,000 per square centimeter, but not many people are going to buy it."

Another approach is to trade higher efficiency for lower cost. Though they generate less power per square inch, thin-film semiconductors require less raw material, making them a cheaper alternative for large photovoltaic installations. Two American companies, First Solar and Nanosolar, say they can now manufacture thin-film solar cells at a cost of around a dollar a watt—tantalizingly close to what's needed to compete with fossil fuels. Looking further ahead, engineers at NREL are working on photovoltaic liquids. "The goal there is to make it the cost of a gallon of paint," Stults said. "The efficiencies won't be 40 or 50 percent. They'll be 10 percent. But if it's cheap, you can paint your walls, hook it up, and go."

Photovoltaic panels aren't limited to individual houses or warehouses. On the northeastern outskirts of Las Vegas, Nellis Air Force Base is supplying an average of 25 percent of its electricity with photovoltaic. On some winter days when there is no need for air-conditioning, 100 percent of the base is solar powered. Last fall, as I looked across the field of 72,416 sun-tracking panels, the wind blowing between the rows, I could see the appeal: There were no oil pipes, heat exchangers, boilers, dynamos, or cooling towers—just solar photons knocking electrons off silicon atoms and generating a current. Constructed in just 26 weeks in 2007 by the SunPower Corporation, the system generates 14.2 megawatts, making it the largest photovoltaic installation in the United States—though only about the 25th largest in the world. Nearly all the bigger ones are in Spain, which, like Germany, has invested heavily in solar power.

None of those plants yet include a storage system. Since photovoltaics produce electricity directly, there is no heat to capture in tanks of molten salt. One option would be to divert some of the photovoltaic current during the day to drive pumps, compressing air into underground caverns. Compressed air has been employed for decades in Germany and Alabama to store the cheaper nighttime output of conventional power plants for use during the daytime peak. At a solar plant the cycle would be reversed: When electricity was needed at night, the pent-up energy from the sunlit hours would be released, rushing forth and spinning a turbine.

Right now people who live off-grid with PV panels on their roofs rely on ordinary batteries to get through the night. In the future they might have solar-powered electrolyzers that split water molecules into hydrogen and oxygen. Recombining the gases in a fuel cell would yield electricity again. The idea is old, but last year Daniel Nocera, a chemist at MIT, reported what may be a breakthrough: a new catalyst that makes splitting water much cheaper. At public lectures Nocera likes to hold up a large plastic water bottle. All of a family's nighttime electricity requirements, he says, could be stored in five of these, with enough left over to run the electric car.

No one knows in detail the future of solar energy. But there is a gathering sense that it is wide open—if we can make the commitment to jump-start the technology. "Originally it seemed like a pie-in-the-sky idea," Michelle Price, the energy manager at Nellis, told me last fall when I toured the base's new photovoltaic plant. "It didn't seem possible." Many things seem possible now.

On a cold December morning west of Frankfurt, Germany, fog hung frozen in the trees, and clouds blocked the sun. Shivering on a ridge above the town of Morbach, I watched the blades of a 330-foot-high wind turbine swoop in and out of the gloom. Down below, a field of photovoltaic panels struggled for light. Who would have thought that Germany would transform itself into the largest producer of photovoltaic power in the world, with a capacity of more than five gigawatts?

A fraction of this power comes from centralized plants like the small one at Morbach or even the sprawling 272-acre Waldpolenz Solar Park, which was constructed recently with thin-film technology on an abandoned Soviet air base near Leipzig. With land at a premium in Germany, solar panels are mounted on rooftops, farmhouses, even on soccer stadiums and along the autobahn. Though dispersed across the countryside, they are connected to the national grid, and utility companies are required to pay even the smallest producers a premium of about 50 euro cents a kilowatt-hour.

"We are being paid for living in this house," said Wolfgang Schnürer, a resident of Solarsiedlung—"solar settlement"—a condominium complex in Freiburg. Outside, snow was sliding off the solar panels that covered the roofs of the development. The day before, Schnürer's system had produced only 5.8 kilowatt-hours, not enough even for a German household. But on a sunny day in May it had yielded more than seven times that much.

After serving coffee and Christmas cookies, Schnürer spread some printouts on the table. In 2008 his personal power plant generated 6,187 kilowatt-hours, more than double what the Schnürers consumed. When the amount they used was subtracted from the amount they produced, they came out more than 2,500 euros (nearly $3,700) ahead.

Sitting at the edge of the Black Forest in the southern part of the country, "sunny Freiburg," as the tourist brochures call it, has been transformed by the solar boom. Across the street from Solarsiedlung, a parking garage and a school are covered with photovoltaic panels. In the older part of town, towering walls of photovoltaics greet visitors at the train station. Nearby, at the Fraunhofer Institute for Solar Energy Systems, the next generation of technology is being developed. In one project, Fresnel lenses are used to concentrate sunlight 500 times, raising the efficiency of a standard photovoltaic panel as high as 23 percent.

It is the demand created by the government's "feed-in tariff" that drives research like this, said Eicke Weber, the institute's director. Anybody who installs a photovoltaic system is guaranteed above-market rates for 20 years—the equivalent of an 8 percent annual return on the initial investment. "It is an ingenious mechanism," Weber said. "I always say the United States addresses the idealists, those who want to save the planet—the Birkenstock crowd. In Germany the law addresses anyone who wants to get 8 percent return on his investment for 20 years."

The most spectacular showcase for the future of solar is probably Plataforma Solúcar, a Spanish solar energy complex on the Andalusian plains. I'd seen photographs of the 11-megawatt power tower called PS10. Rising 377 feet high, it is surrounded by 624 sun-tracking mirrors that reflect light beams toward its crown, igniting a glow that shines like a new star. Next to it, PS20 has since been completed with twice as many heliostats and double the power. But as I crested a hilltop about 15 miles west of Seville, I saw that the German weather had followed me. The valley was enveloped in fog—a reminder that even in torrid southern Spain, solar will always have to be supplemented by storage and other forms of power.

"We had a problem last night—no more tower," said Valerio Fernández, director of the plant, which is owned by Abengoa Solar, as he met me at the gate. He laughed as we looked up at PS10, its head lost in the clouds. On a normal day, the power focused on the tower could reach four megawatts per square meter—far more than can be safely utilized. PS10's operators have to limit the flux to avoid melting the receiver.

Power towers are a different version of solar thermal, another way to use sunlight to make steam. Although parabolic troughs are well proven for large, flat areas, power towers can be fit to hilly terrain, the mirrors individually aligned to converge on the elevated boiler. Because a tower heats steam to higher temperatures, it is potentially more efficient.

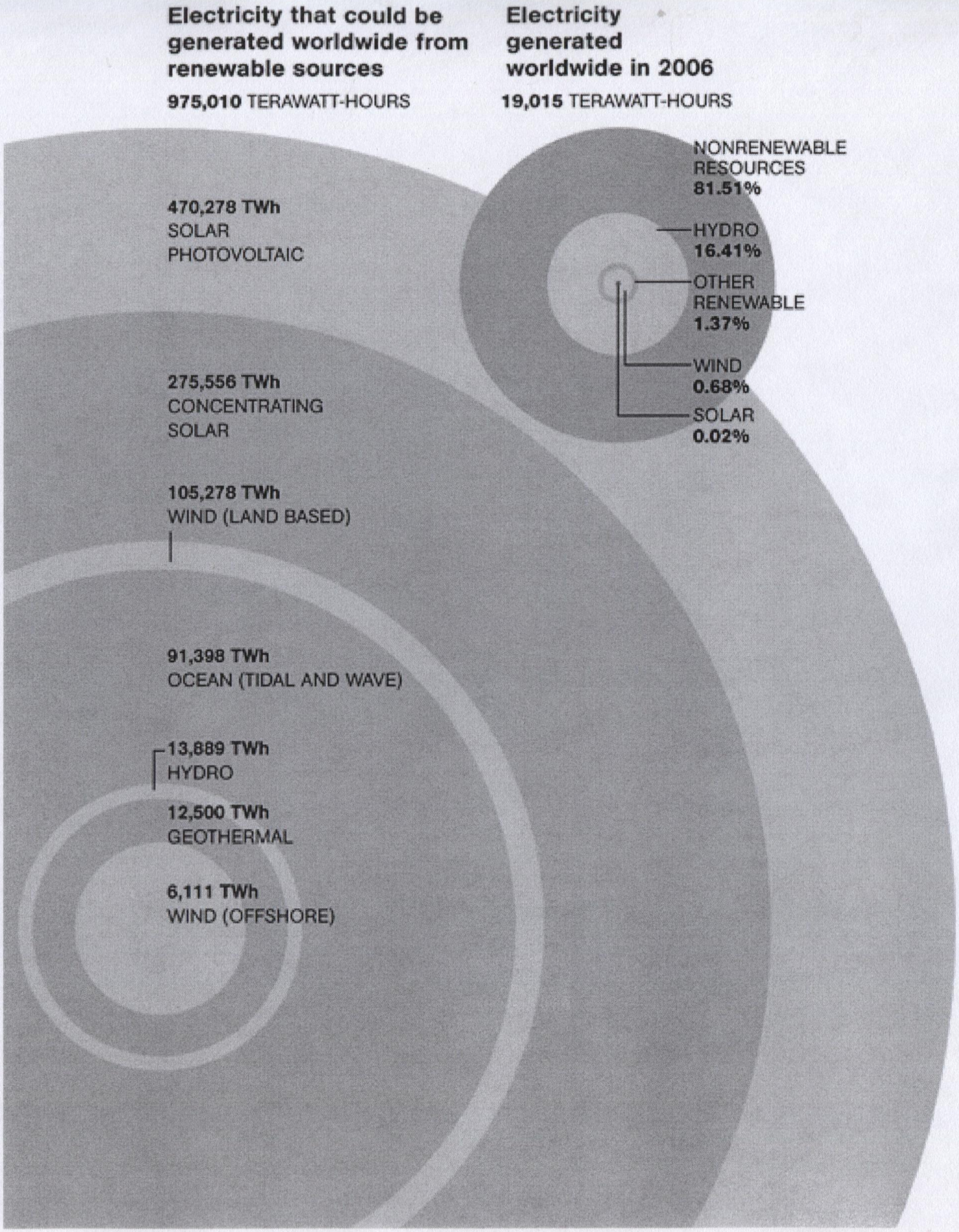
With the solar industry still in its infancy, however, Abengoa Solar is hedging its bets. Not far from the power towers, cranes were assembling rows of parabolic troughs. Behind PS10 stretched a field of advanced photovoltaics that track the sun on two axes—north-south as well as east-west—to ensure optimal exposure throughout the year. Each panel was fitted with mirrors or Fresnel lenses to intensify the light. "Taking profit from every one of the rays of sun—that's our goal," Fernández said.

Back home in the United States I read a magazine article challenging the country to move faster in harnessing the sun: "Every hour, it floods the earth with a deluge of thermal energy equal to 21 billion tons of coal," the writer had calculated. "The enormous output of solar energy is almost impossible to conceive." Illustrated with a drawing of a futuristic solar plant with enormous steam-generating mirrors, the article was entitled "Why Don't We Have…Sun Power?" It was dated September 1953.

This time we might just make it. Last February, BrightSource Energy signed contracts with Southern California Edison for a series of power towers in southwestern deserts that could eventually provide 1.3 gigawatts of power, equal to a large coal-fired plant. Meanwhile, Pacific Gas and Electric has commissioned more than 1.8 gigawatts of parabolic troughs, photovoltaics, and BrightSource power towers. Environmentalists are already preparing to fight some of these projects; they would all cover large swaths of desert, and some might use a lot of scarce water for cooling. Like any form of power generation, solar has its trade-offs.

And it still has a long way to go. While I was in Nevada, I drove out to Hoover Dam—an early mass producer of renewable electricity—and joined a tour descending deep inside. At the bottom the torrent of Colorado River water falling from Lake Mead was spinning two parallel rows of giant turbines. Just one turbine puts out 130 megawatts, twice the power of Nevada Solar One.

But Hoover Dam left me feeling hopeful. Back on top, as I read the tarnished brass plaques and admired the art deco architecture, I thought about how this country had met the challenges of the Great Depression of the 1930s. The New Deal, as that earlier stimulus package was called, included not only Hoover but also the Tennessee Valley Authority, which brought hydroelectric power to the Southeast, and the Rural Electrification Administration, which strung power lines into the heartland. At a time of economic calamity, the nation's energy landscape was transformed. Seven decades later we still reap the benefits every time we flip a switch.



◂ RANKING THE RENEWABLES

The sun's potential for power generation eclipses that of all other renewable energy sources. But for now solar power barely registers in the world's energy portfolio (inset graph). It accounts for only a small fraction of a percent of total electrical output—much less than hydropower or wind energy, which are cheaper to produce.

NOTE: ONE TERAWATT-HOUR = 1,000 GIGAWATT-HOURS = 1 BILLION KILOWATT-HOURS. ONE KILOWATT-HOUR WILL POWER A 100-WATT LIGHTBULB FOR TEN HOURS.

SEAN McNAUGHTON, NG STAFF

GRAPHIC BY 5W INFOGRAPHICS

SOURCES: NASA (WORLD MAP); *WORLD ENERGY STATISTICS AND BALANCES* © OECD/IEA, 2008; NATIONAL RENEWABLE ENERGY LABORATORY (SOUTHWEST MAP); ECOFYS (POTENTIAL GENERATION)

THE SOLAR SOUTHWEST

Solar advocates say the desert Southwest could light the entire U.S. Thousands of square miles there (colored areas) are not only sunny but also flat and undeveloped enough for concentrating-solar plants. Some environmentalists oppose the land- and water-hungry projects and the new transmission lines that would be needed.

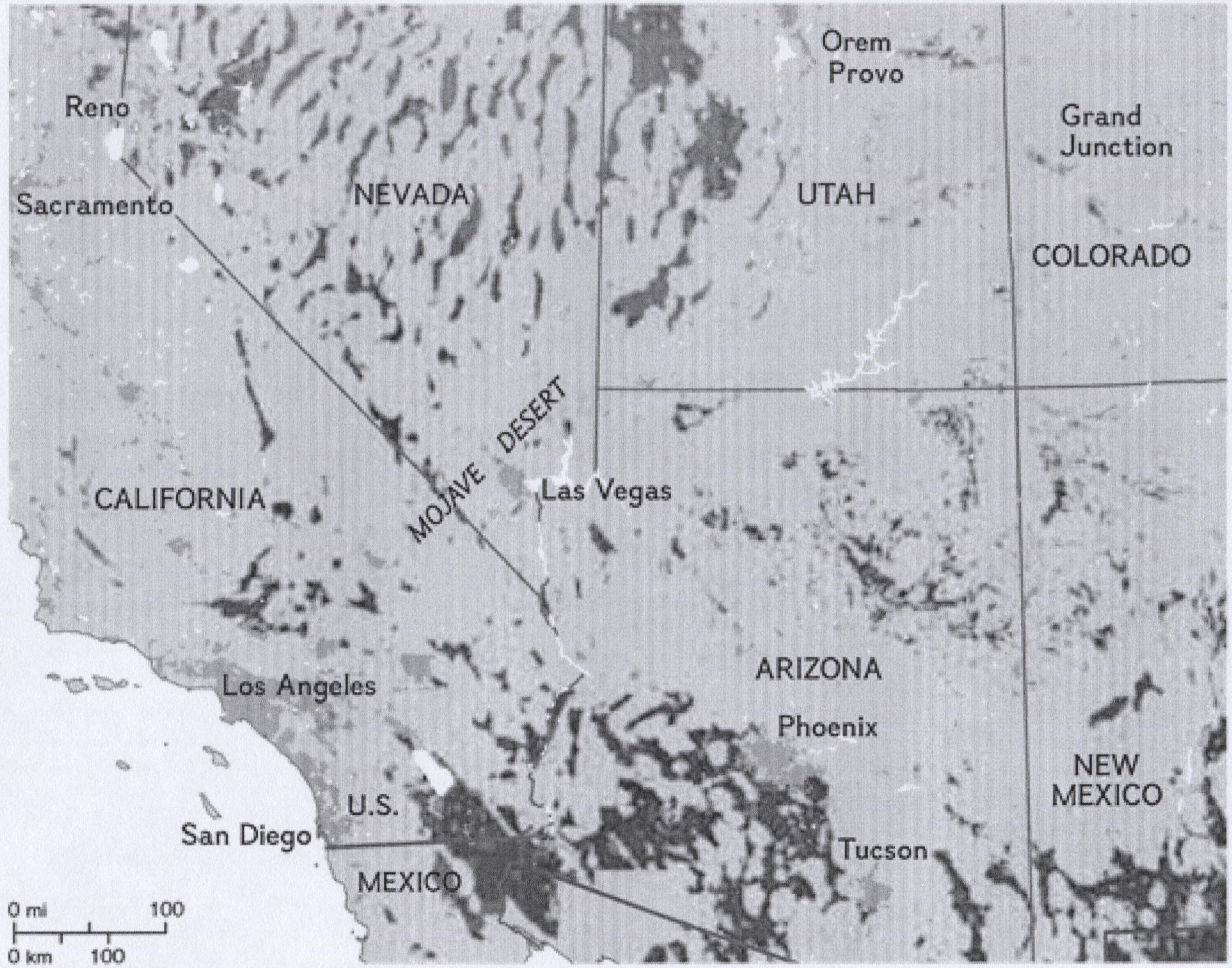
SOLAR RADIATION SUITABLE FOR USE IN CONCENTRATING-SOLAR PLANTS

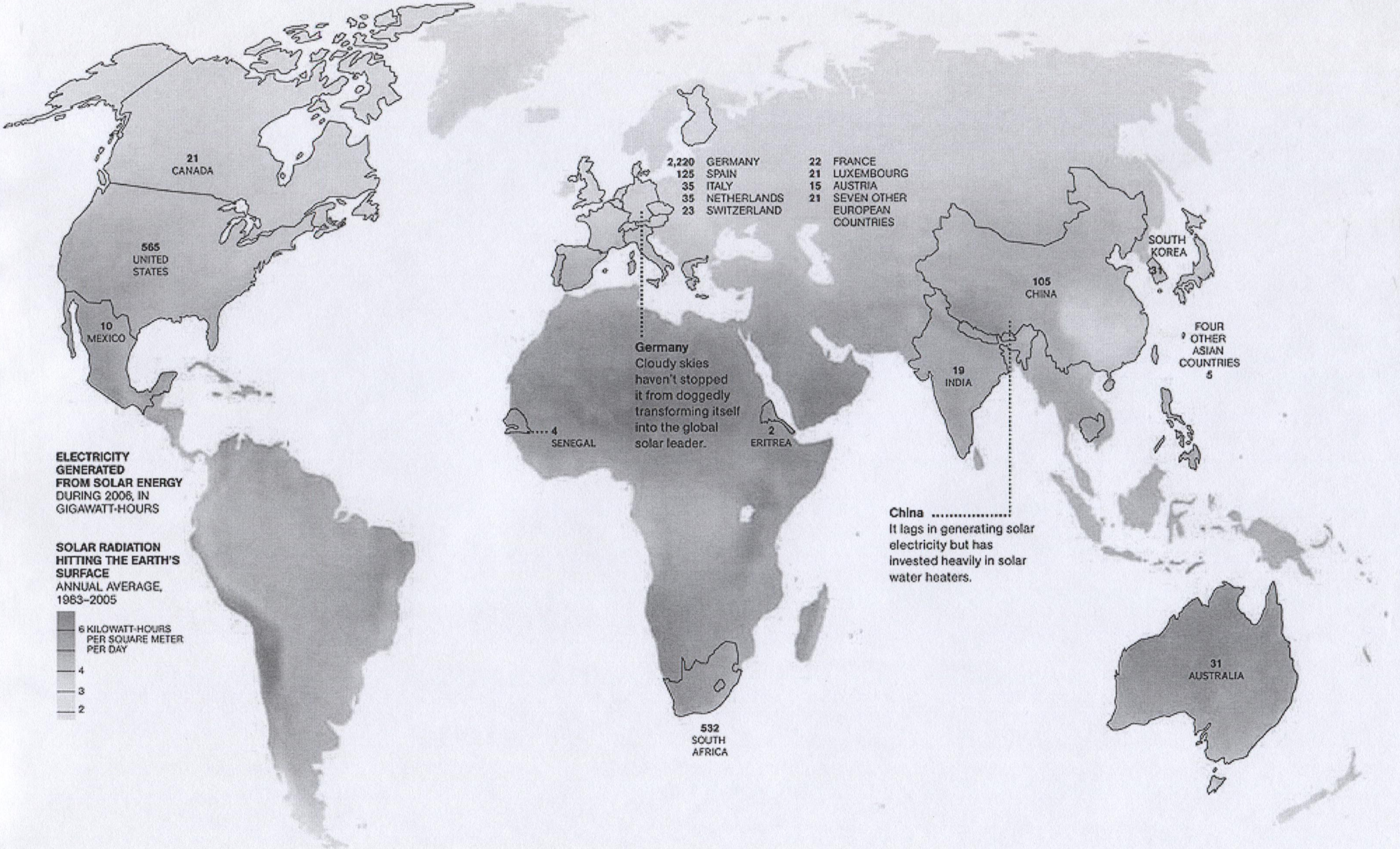
8 KILOWATT-HOURS PER SQUARE METER PER DAY

7

6

POPULATED AREAS





ELECTRICITY GENERATED FROM SOLAR ENERGY DURING 2006, IN GIGAWATT-HOURS
SOLAR RADIATION HITTING THE EARTH'S SURFACE ANNUAL AVERAGE, 1983–2005
6 KILOWATT-HOURS PER SQUARE METER PER DAY
4
3
2
21 CANADA
565 UNITED STATES
10 MEXICO
4 SENEGAL
2 ERITREA
532 SOUTH AFRICA
2,220 GERMANY
125 SPAIN
35 ITALY
35 NETHERLANDS
23 SWITZERLAND
22 FRANCE
21 LUXEMBOURG
15 AUSTRIA
21 SEVEN OTHER EUROPEAN COUNTRIES
Germany
Cloudy skies haven't stopped it from doggedly transforming itself into the global solar leader.
105 CHINA
19 INDIA
SOUTH KOREA 31
FOUR OTHER ASIAN COUNTRIES 5
China
It lags in generating solar electricity but has invested heavily in solar water heaters.
31 AUSTRALIA