FEATURE

Powering the Future

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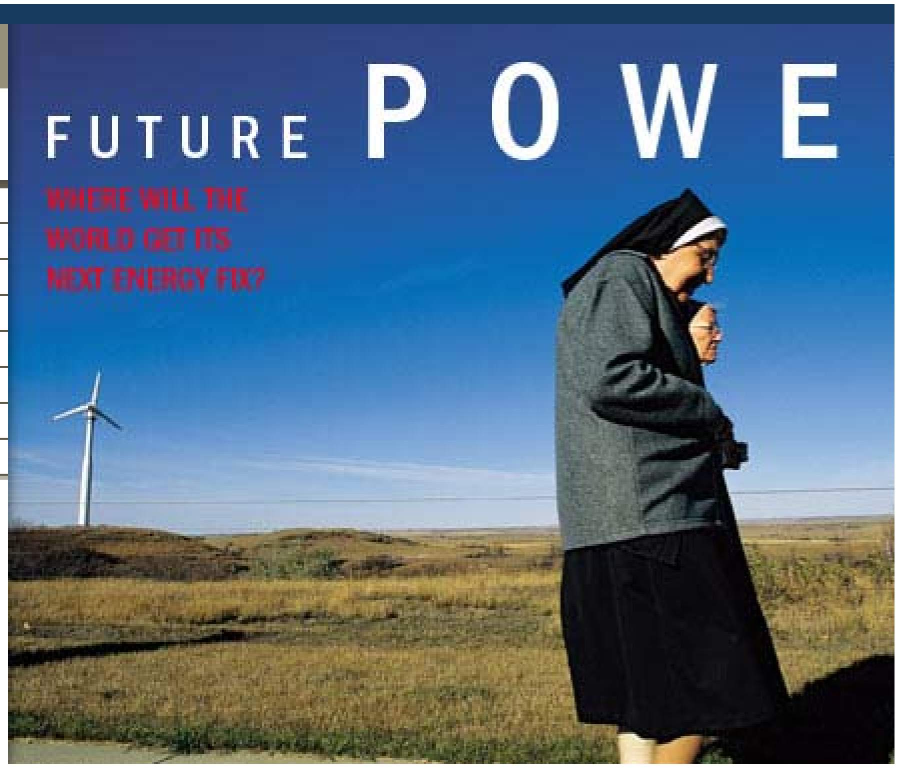
Feature Main Page
Photo Gallery
On Assignment
Learn More
Forum
Poll
Postcards
Newsmakers

What's Your Energy IQ?



By **Michael Parfit** Photographs by **Sarah Leen**

Where on Earth can our energy-hungry society turn to repla oil, coal, and natural gas?

Freedom!

I stand in a cluttered room surrounded by the debris of electrical enthusiasm: wire peelings, snippets of copper, yellow connectors, insulated pliers. For me these are the tools of freedom. I have just installed a dozen solar panels on my roof, and they work. A meter shows that 1,285 watts of power are blasting straight from the sun into my system, charging my batteries, cooling my refrigerator, humming through my computer, liberating my life.

The euphoria of energy freedom is addictive. Don't get me wrong; I love fossil fuels. I live on an island that happens to have no utilities, but otherwise my wife and I have a normal American life. We don't want propane refrigerators, kerosene lamps, or composting toilets. We want a lot of electrical outlets and a cappuccino maker. But when I turn on those panels, wow!

Maybe that's because for me, as for most Americans, one energy crisis or another has shadowed most of the past three decades. From the OPEC crunch of the 1970s to the skyrocketing cost of oil and gasoline today, the world's concern over energy has haunted presidential speeches, congressional campaigns, disaster books, and my own sense of well-being with the same kind of gnawing unease that characterized the Cold War.

As *National Geographic* reported in June 2004, oil, no longer cheap, may soon decline. Instability where most oil is found, from the Persian Gulf to Nigeria to Venezuela, makes this lifeline fragile. Natural gas can be hard to transport and is prone to shortages. We won't run out of coal anytime soon, or the largely untapped deposits of tar sands and oil shale. But it's clear that the carbon dioxide spewed by coal and other fossil fuels is warming the planet, as this magazine reported last September.

Cutting loose from that worry is enticing. With my new panels, nothing stands between me and limitless energy—no foreign nation, no power company, no carbon-emission guilt. I'm free!

Well, almost. Here comes a cloud.

Shade steals across my panels and over my heart. The meter shows only 120 watts. I'm going to have to start the generator and burn some more gasoline. This isn't going to be easy after all.

The trouble with energy freedom is that it's addictive; when you get a little, you want a lot. In microcosm I'm like people in government, industry, and private life all over the world, who have tasted a bit of this curious and compelling kind of liberty and are determined to find more.

Some experts think this pursuit is even more important than the war on terrorism. "Terrorism doesn't threaten the viability of the heart of our high-technology lifestyle," says Martin Hoffert, a professor of physics at New York University. "But energy really does."

Energy conservation can stave off the day of reckoning, but in the end you can't conserve what you don't have. So Hoffert and others have no doubt: It's time to step up the search for the next great fuel for the hungry engine of humankind.

Is there such a fuel? The short answer is no. Experts say it like a mantra: "There is no silver bullet." Though a few true believers claim that only vast conspiracies or lack of funds stand between us and endless energy from the vacuum of space or the core of the Earth, the truth is that there's no single great new fuel waiting in the heart of an equation or at the end of a drill bit.

Enthusiasm about hydrogen-fueled cars may give the wrong impression. Hydrogen is not a source of energy. It's found along with oxygen in plain old water, but it isn't there for the taking. Hydrogen has to be freed before it is useful, and that costs more energy than the hydrogen gives back. These days, this energy comes mostly from fossil fuels. No silver bullet there.

The long answer about our next fuel is not so grim, however. In fact, plenty of contenders for the energy crown now held by fossil fuels are already at hand: wind, solar, even nuclear, to name a few. But the successor will have to be a congress, not a king. Virtually every energy expert I met did something unexpected: He pushed not just his own specialty but everyone else's too.

"We're going to need everything we can get from biomass, everything we can get from solar, everything we can get from wind," says Michael Pacheco, director of the National Bioenergy Center, part of the National Renewable Energy Laboratories (NREL) in Golden, Colorado. "And still the question is, can we get enough?"

The big problem is big numbers. The world uses some 320 billion kilowatt-hours of energy a day. It's equal to about 22 bulbs burning nonstop for every person on the planet. No wonder the sparkle is seen from space. Hoffert's team estimates that within the next century humanity could use three times that much. Fossil fuels have met the growing demand because they pack millions of years of the sun's energy into a compact form, but we will not find their like again.

Fired up by my taste of energy freedom, I went looking for technologies that can address those numbers. "If you have a big problem, you must give a big answer," says a genial energy guru named Hermann Scheer, a member of the German parliament. "Otherwise people don't believe."

The answers are out there. But they all require one more thing of us humans who huddle around the fossil fuel fire: We're going to have to make a big leap—toward a different kind of world.

SOLAR: FREE ENERGY, AT A PRICE

On a cloudy day near the city of Leipzig in the former East Germany, I walked across a field of fresh grass, past a pond where wild swans fed. The field was also sown with 33,500 photovoltaic panels, planted in rows like silver flowers all turned sunward, undulating gently across the contours of the land. It's one of the largest solar arrays ever. When the sun emerges, the field produces up to five megawatts of power, and it averages enough for 1,800 homes.

Nearby are gaping pits where coal was mined for generations to feed power plants and factories. The skies used to be brown with smoke and acrid with sulfur. Now the mines are being turned into lakes, and power that once came from coal is made in a furnace 93 million miles (150 million kilometers) away.

Solar electric systems catch energy directly from the sun—no fire, no emissions. Some labs and companies are trying out the grown-up version of a child's magnifying glass: giant mirrored bowls or troughs to concentrate the sun's rays, producing heat that can drive a generator. But for now, sun power mostly means solar cells.

The idea is simple: Sunlight falling on a layer of semiconductor jostles electrons, creating a current. Yet the cost of the cells, once astronomical, is still high. My modest system cost over $15,000, about $10 a watt of capacity, including batteries to store power for when the sun doesn't shine.

Like most things electronic, solar power has been getting cheaper. "Thirty years ago it was cost-effective on satellites," says Daniel Shugar, president of PowerLight Corporation, a fast-growing California company that has built solar installations for clients including Toyota and Target. "Today it can be cost-effective for powering houses and businesses," at least where utility power is expensive or unavailable. Tomorrow, he says, it will make sense for almost everyone.

Martin Roscheisen, CEO of a company called Nanosolar, sees that future in a set of red-topped vials, filled with tiny particles of semiconductor. "I put some of that on my finger, and it disappeared right into my skin," he says. He won't say exactly what the particles are, but the "nano" in the company name is a hint: They are less than a hundred nanometers across—about the size of a virus, and so small they slip right through skin.

Roscheisen believes those particles promise a low-cost way to create solar cells. Instead of making the cells from slabs of silicon, his company will paint the particles onto a foil-like material, where they will self-assemble to create a semiconductor surface. The result: a flexible solar-cell material 50 times thinner than today's solar panels. Roscheisen hopes to sell it in sheets, for about 50 cents a watt.

"Fifty cents a watt is kind of the holy grail," says David Pearce, president and CEO of Miasolé, one of many other companies working on "thin-film" solar cells. At that price solar could compete with utilities and might take off. If prices continued to drop, solar cells might change the whole idea of energy by making it cheap and easy for individuals to gather for themselves. That's what techies call a "disruptive technology."

"Automobiles were disruptive to the horse and buggy business," Dan Shugar says. "PCs were disruptive to the typewriter industry. We believe solar electric systems will be disruptive to the energy industry."

Yet price isn't the only hurdle solar faces. There are the small matters of clouds and darkness, which call for better ways of storing energy than the bulky lead-acid batteries in my system. But even if those hurdles are overcome, can solar really make the big energy we need?

With solar now providing less than one percent of the world's energy, that would take "a massive (but not insurmountable) scale-up," NYU's Hoffert and his colleagues said in an article in *Science.* At present levels of efficiency, it would take about 10,000 square miles (30,000 square kilometers) of solar panels—an area bigger than Vermont—to satisfy all of the United States' electricity needs. But the land requirement sounds more daunting than it is: Open country wouldn't have to be covered. All those panels could fit on less than a quarter of the roof and pavement space in cities and suburbs.

WIND: FEAST OR FAMINE

Wind, ultimately driven by sun-warmed air, is just another way of collecting solar energy, but it works on cloudy days. One afternoon I stood in a field near Denmark's west coast under a sky so dark and heavy it would have put my own solar panels into a coma. But right above me clean power was being cranked out by the megawatt. A blade longer than an airplane wing turned slowly in a strong south breeze. It was a wind turbine.

The turbine's lazy sweep was misleading. Each time one of the three 130-foot (40-meter) blades swung past, it hissed as it sliced the air. Tip speed can be well over 100 miles (160 kilometers) an hour. This single tower was capable of producing two megawatts, almost half the entire output of the Leipzig solar farm.

In Denmark, turning blades are always on the horizon, in small or large groups, like spokes of wheels rolling toward a strange new world. Denmark's total installed wind power is now more than 3,000 megawatts—about 20 percent of the nation's electrical needs. All over Europe generous incentives designed to reduce carbon emissions and wean economies from oil and coal have led to a wind boom. The continent leads the world in wind power, with almost 35,000 megawatts, equivalent to 35 large coal-fired power plants. North America, even though it has huge potential for wind energy, remains a distant second, with just over 7,000 megawatts. With the exception of hydroelectric power—which has been driving machines for centuries but has little room to grow in developed countries—wind is currently the biggest success story in renewable energy.

"When I started in 1987, I spent a lot of time sitting in farmers' houses until midnight talking to the neighbors, just selling one turbine," says Hans Buus. He's director of project development for a Danish energy company called Elsam. "I would not have been able to imagine the level it is today."

He means not only the number of turbines but also their sheer size. In Germany I saw a fiberglass-and-steel prototype that stands 600 feet (200 meters) tall, has blades 200 feet (60 meters) long, and can generate five megawatts. It's not just a monument to engineering but also an effort to overcome some new obstacles to wind power development.

One is aesthetic. England's Lake District is a spectacular landscape of bracken-clad hills and secluded valleys, mostly protected as a national park. But on a ridge just outside the park, though not outside the magnificence, 27 towers are planned, each as big as the two-megawatt machine in Denmark. Many locals are protesting. "This is a high-quality landscape," says one. "They shouldn't be putting those things in here."

Danes seem to like turbines more than the British, perhaps because many

Danish turbines belong to cooperatives of local residents. It's harder to say "not in my backyard" if the thing in your backyard helps pay for your house. But environmental opposition is not the only trouble facing wind development. Across Europe many of the windiest sites are already occupied. So the five-megawatt German machine is designed to help take wind power away from the scenery and out to abundant new sites at sea.

Many coastlines have broad areas of shallow continental shelf where the wind blows more steadily than on land and where, as one wind expert puts it, "the seagulls don't vote." (Real voters, however, sometimes still object to the sight of towers on the horizon.) It costs more to build and maintain turbines offshore than on land, but an underwater foundation for a five-megawatt tower is cheaper per megawatt than a smaller foundation. Hence the German giant.

There are other challenges. Like sailboats, wind turbines can be becalmed for days. To keep the grid humming, other sources, such as coal-fired power plants, have to stand ready to take up the slack. But when a strong wind dumps power into the grid, the other generators have to be turned down, and plants that burn fuel are not quickly adjustable. A wind-power bonanza can become a glut. Denmark, for example, is sometimes forced to unload power at uneconomic rates to neighbors like Norway and Germany.

What's needed for wind as well as solar is a way to store a large energy surplus. Technology already exists to turn it into fuels such as hydrogen or ethanol or harness it to compress air or spin flywheels, banking energy that can later churn out electricity. But most systems are still decades from becoming economically feasible.

On the plus side, both wind and solar can provide what's called distributed energy: They can make power on a small scale near the user. You can't have a private coal plant, but you can have your own windmill, with batteries for calm days. The more houses or communities make their own wind power, the smaller and cheaper central power plants and transmission lines can be.

In Europe's big push toward wind power, the turbines keep growing. But in Flagstaff, Arizona, Southwest Windpower makes turbines with blades you can pick up in one hand. The company has sold about 60,000 of the little turbines, most of them for off-grid homes, sailboats, and remote sites like lighthouses and weather stations. At 400 watts apiece they can't power more than a few lights.

But David Calley, Southwest's president, whose father built his first wind turbine out of washing machine parts, is testing a new product he calls an energy appliance. It will stand on a tower as tall as a telephone pole, produce up to two kilowatts in a moderate wind, and come with all the electronics needed to plug it into the house.

Many U.S. utilities are required to pay for power that individuals put back into the grid, so anyone in a relatively breezy place could pop up the energy appliance in the yard, use the power when it's needed, and feed it back into the grid when it's not. Except for the heavy loads of heating and air-conditioning, this setup could reduce a home's annual power bill to near zero. If, as Calley hopes, he can ultimately sell the energy appliance for under $3,000, it would pay for itself with energy savings within a few years.

Somewhere in this mix of the grand and the personal, there may be big numbers in wind too.

BIOMASS: FARMING YOUR FUEL

In Germany, driving from the giant wind turbine near Hamburg to Berlin, I regularly got an odd whiff: the sort-of-appetizing scent of fast food. It was a puzzle until a tanker truck passed, emblazoned with the word "biodiesel." The scent was of burning vegetable oil. Germany uses about 450 million gallons (1,700 million liters) of biodiesel a year, about 3 percent of its total diesel consumption.

Biomass energy has ancient roots. The logs in your fire are biomass. But today biomass means ethanol, biogas, and biodiesel—fuels as easy to burn as oil or gas, but made from plants. These technologies are proven. Ethanol produced from corn goes into gasoline blends in the U.S.; ethanol from sugarcane provides 50 percent of automobile fuel in Brazil. In the U.S. and other nations, biodiesel from vegetable oil is burned, pure or mixed with regular diesel, in unmodified engines. "Biofuels are the easiest fuels to slot into the existing fuel system," says Michael Pacheco, the National Bioenergy Center director.

What limits biomass is land. Photosynthesis, the process that captures the sun's energy in plants, is far less efficient per square foot than solar panels, so catching energy in plants gobbles up even more land. Estimates suggest that powering all the world's vehicles with biofuels would mean doubling the amount of land devoted to farming.

At the National Bioenergy Center, scientists are trying to make fuel-farming more efficient. Today's biomass fuels are based on plant starches, oils, and sugars, but the center is testing organisms that can digest woody cellulose, abundant in plants, so that it too could yield liquid fuel. More productive fuel crops could help as well.

One is switchgrass, a plant native to North America's prairies that grows faster and needs less fertilizer than corn, the source of most ethanol fuel made in the U.S. It also thrives on land unfit for other crops and does double duty as a source of animal food, further reducing the pressure on farmland.

"Preliminary results look promising," says Thomas Foust, the center's technology manager. "If you increase automobile efficiency to the level of a hybrid and go with the switchgrass crop mix, you could meet two-thirds of the U.S. transportation fuel demand with no additional land."

But technically possible doesn't mean politically feasible. From corn to sugarcane, all crops have their own lobbyists. "We're looking down a lot of alleys," says Pacheco. "And every alley has its own vested interest group. Frankly, one of the biggest challenges with biomass is that there are so many options."

NUCLEAR: STILL A CONTENDER

Nuclear fission appeared to lead the race as an energy alternative decades ago, as countries began building reactors. Worldwide, about 440 plants now generate 16 percent of the planet's electric power, and some countries have gone heavily nuclear. France, for instance, gets 78 percent of its electricity from fission.

The allure is clear: abundant power, no carbon dioxide emissions, no blots on the landscape except an occasional containment dome and cooling tower. But along with its familiar woes—the accidents at Three Mile Island and Chornobyl, poor economics compared with fossil fuel plants, and the challenge of radioactive waste disposal—nuclear power is far from renewable. The readily available uranium fuel won't last much more than 50 years.

Yet enthusiasm is reviving. China, facing a shortage of electric power, has started to build new reactors at a brisk pace—one or two a year. In the U.S., where some hydrogen-car boosters see nuclear plants as a good source of energy for making hydrogen from water, Vice President Dick Cheney has called for "a fresh look" at nuclear. And Japan, which lacks its own oil, gas, and coal, continues to encourage a fission program. Yumi Akimoto, a Japanese elder statesman of nuclear chemistry, saw the flash of the bomb at Hiroshima as a boy yet describes nuclear fission as "the pillar of the next century."

In the town of Rokkasho at the northernmost tip of Honshu Island, Japan is working to get around the limits of the uranium supply. Inside a new 20-

billion-dollar complex, workers wear pale blue work suits and an air of patient haste. I looked in on cylindrical centrifuges for enriching uranium and a pool partly filled with rods of spent nuclear fuel, cooling. Spent fuel is rich in plutonium and leftover uranium—valuable nuclear material that the plant is designed to salvage. It will "reprocess" the spent fuel into a mixture of enriched uranium and plutonium called MOX, for mixed oxide fuel. MOX can be burned in some modern reactors and could stretch the fuel supply for decades or more.

Reprocessing plants in other countries also turn spent fuel into MOX. But those plants originally made plutonium for nuclear weapons, so the Japanese like to say that theirs, due to start up in 2007, is the first such plant built entirely for peaceful use. To assure the world that it will stay that way, the Rokkasho complex includes a building for inspectors from the International Atomic Energy Agency, the United Nations' nuclear watchdog, who will make certain that none of the plutonium is diverted for weapons.

That doesn't satisfy nuclear energy opponents. Opposition has mounted in Japan after fatal accidents at the country's nuclear plants, including one that killed two workers and exposed others to radiation. Shortly after my visit to Rokkasho, about a hundred protesters marched outside the plant in a blizzard.

A bigger controversy would greet what some nuclear proponents think is a crucial next step: a move to breeder reactors. Breeders can make more fuel than they consume, in the form of plutonium that can be extracted by reprocessing the spent fuel. But experimental breeder reactors have proved to be temperamental, and a full-scale breeder program could be an arms-control nightmare because of all the plutonium it would put in circulation.

Akimoto, for one, believes that society has to get comfortable with fuel reprocessing if it wants to count on nuclear energy. He spoke to me through an interpreter, but to emphasize this point he jumped into English: "If we are going to accept nuclear power, we have to accept the total system. Sometimes we want to get the first crop of fruit but forget how to grow the trees."

FUSION: THE FIRE SOME TIME

Fusion is the gaudiest of hopes, the fire of the stars in the human hearth. Produced when two atoms fuse into one, fusion energy could satisfy huge chunks of future demand. The fuel would last millennia. Fusion would produce no long-lived radioactive waste and nothing for terrorists or governments to turn into weapons. It also requires some of the most complex machinery on Earth.

A few scientists have claimed that cold fusion, which promises energy from a simple jar instead of a high-tech crucible, might work. The verdict so far: No such luck. Hot fusion is more likely to succeed, but it will be a decades-long quest costing billions of dollars.

Hot fusion is tough because the fuel—a kind of hydrogen—has to be heated to a hundred million degrees Celsius or so before the atoms start fusing. At those temperatures the hydrogen forms a roiling, unruly vapor of electrically charged particles, called plasma. "Plasma is the most common state of matter in the universe," says one physicist, "but it's also the most chaotic and the least easily controlled." Creating and containing plasma is so challenging that no fusion experiment has yet returned more than 65 percent of the energy it took to start the reaction.

Now scientists in Europe, Japan, and the U.S. are refining the process, learning better ways to control plasma and trying to push up the energy output. They hope that a six-billion-dollar test reactor called ITER will get the fusion bonfire blazing—what physicists call "igniting the plasma." The next step would be a demonstration plant to actually generate power, followed by commercial plants in 50 years or so.

"I am 100 percent sure we can ignite the plasma," says Jerome Pamela, the project manager of a fusion machine called the Joint European Torus, or JET, at Britain's Culham Science Center. "The biggest challenge is the transition between the plasma and the outside world." He means finding the right materials for the lining of the ITER plasma chamber, where they will have to withstand a bombardment of neutrons and transfer heat to electric generators.

At Culham I saw an experiment in a tokamak, a device that cages plasma in a magnetic field shaped like a doughnut—the standard design for most fusion efforts, including ITER. The physicists sent a huge electrical charge into the gas-filled container, a scaled-down version of JET. It raised the temperature to about ten million degrees Celsius, not enough to start fusion but enough to create plasma.

The experiment lasted a quarter of a second. A video camera shooting 2,250 frames a second captured it. As it played back, a faint glow blossomed in the chamber, wavered, grew into a haze visible only on its cooling edges, and vanished.

It was—well, disappointing. I had expected the plasma to look like a movie shot of an exploding automobile. This was more like a ghost in an English paneled library.

But this phantom was energy incarnate: the universal but elusive magic that all our varied technologies—solar, wind, biomass, fission, fusion, and many others large or small, mainstream or crazy—seek to wrestle into our service.

Taming that ghost is not just a scientific challenge. The ITER project has been held up by a seemingly simple problem. Since 2003 the participating countries—including much of the developed world—have been deadlocked over where to build the machine. The choice has come down to two sites, one in France and one in Japan.

As all energy experts will tell you, this proves a well-established theory. There's only one force tougher to manage than plasma: politics.

Although some politicians believe the task of developing the new energy technologies should be left to market forces, many experts disagree. That's not just because it's expensive to get new technology started, but also because government can often take risks that private enterprise won't.

"Most of the modern technology that has been driving the U.S. economy did not come spontaneously from market forces," NYU's Martin Hoffert says, ticking off jet planes, satellite communications, integrated circuits, computers. "The Internet was supported for 20 years by the military and for 10 more years by the National Science Foundation before Wall Street found it."

Without a big push from government, he says, we may be condemned to rely on increasingly dirty fossil fuels as cleaner ones like oil and gas run out, with dire consequences for the climate. "If we don't have a proactive energy policy," he says, "we'll just wind up using coal, then shale, then tar sands, and it will be a continually diminishing return, and eventually our civilization will collapse. But it doesn't have to end that way. We have a choice."

It's a matter of self-interest, says Hermann Scheer, the German member of parliament. "I don't appeal to the people to change their conscience," he said in his Berlin office, where a small model of a wind turbine turned lazily in a window. "You can't go around like a priest." Instead, his message is that nurturing new forms of energy is necessary for an environmentally and economically sound future. "There is no alternative."

Already, change is rising from the grass roots. In the U.S., state and local governments are pushing alternative energies by offering subsidies and requiring that utility companies include renewable sources in their plans. And in Europe financial incentives for both wind and solar energy have broad support even though they raise electric bills.

Alternative energy is also catching on in parts of the developing world where it's a necessity, not a choice. Solar power, for example, is making inroads in African communities lacking power lines and generators. "If you want to overcome poverty, what do people need to focus on?" asks Germany's environment minister, Jürgen Trittin. "They need fresh water and they need energy. For filling the needs of remote villages, renewable energy is highly competitive."

In developed countries there's a sense that alternative energy—once seen as a quaint hippie enthusiasm—is no longer alternative culture. It's edging into the mainstream. The excitement of energy freedom seems contagious.

One afternoon last year, near a village north of Munich, a small group of townspeople and workers inaugurated a solar facility. It would soon surpass the Leipzig field as the largest in the world, with six megawatts of power.

About 15 people gathered on a little man-made hill beside the solar farm and planted four cherry trees on the summit. The mayor of the tidy nearby town brought out souvenir bottles of schnapps. Almost everyone had a swig, including the mayor.

Then he said he would sing to the project's construction supervisor and a landscape artist, both American women. The two women stood together, grinning, with the field of solar panels soaking up energy behind them. The German mayor straightened his dark suit, and the other men leaned on their shovels.

Fifty years ago, I thought, there were still bombed-out ruins in the cities of Europe. The Soviet Union was planning Sputnik. Texas oil was $2.82 a barrel. At the most, we have 50 years to make the world over again. But people change, adapt, and make crazy new stuff work. I thought about Dan Shugar talking about disruptive technologies. "There's a sense of excitement," he had said. "There's a sense of urgency. There's a sense that we cannot fail."

On the hilltop, the mayor took a deep breath. He sang, in a booming tenor, without missing a note or a word, the entire song "O Sole Mio." Everyone cheered.

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Top