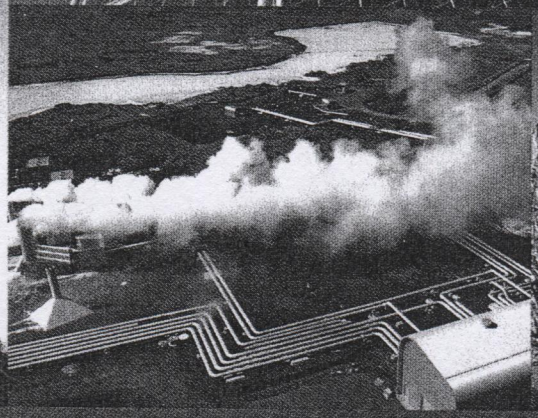
THE POWER OF RENEWA



BLES

The need to tackle global climate change and energy security makes developing alternatives to fossil fuels crucial.

HERE IS HOW THEY STACK UP

BY MATTHEW L. WALD

Illustrations by Don Foley

Renewable energy, such as from photovoltaic electricity and ethanol, today supplies less than 7 percent of U.S. consumption. If we leave aside hydroelectric power, it is under 4.5 percent. Globally, renewables provide only about 3.5 percent of electricity and even less of transportation fuels.

But increasing that fraction for the U.S.—as seems necessary for managing greenhouse gases, trade deficits and dependence on foreign suppliers—has at least three tricky components. The obvious one is how to capture the energy of wind, sun and crops economically. After that, the energy has to be moved from where it is easily gathered, such as the sunny American Southwest or the windy High Plains, to the places it can be used. And the third is to convert it into convenient forms. Most prominently in the last category, electricity for transportation has to be loaded into cars and trucks, either through batteries or perhaps as hydrogen.

In some ways, the field is galloping ahead. A recent study sponsored by the United Nations found that global investment in renewable energy in 2007 was $148.4 billion, up 60 percent from 2006. But new wind turbines and solar cells are joining an infrastructure with coal-fired power plants that seem to run more hours every year and that are multiplying as well.

And although solar energy and especially wind have declined steeply in price over the past few years, they are competitive only when given subsidies or mandates. U.S. residential customers pay an average of 11 cents per kilowatt-hour (kWh) for power from a mix of coal, natural gas, nuclear and hydroelectric sources, but renewables are far pricier. Of course, all forms of energy get a carrot-and-stick treatment from governments, whether to provide work for coal miners or to prove that splitting the atom is useful for something besides bombs. But in many places, renewables get something even better: quotas. And rising prices for traditional fuels could help, raising the market to reach the renewables' costs.

A carbon charge would also help; each $10 tax on a ton of carbon dioxide emitted would raise the price of a kilowatt-hour from a coal-fired power plant by about a penny. But the scale of the transformation is immense; in energy content, coal production is about 70 times larger than wind-energy production. The numbers for oil and natural gas are similarly daunting.

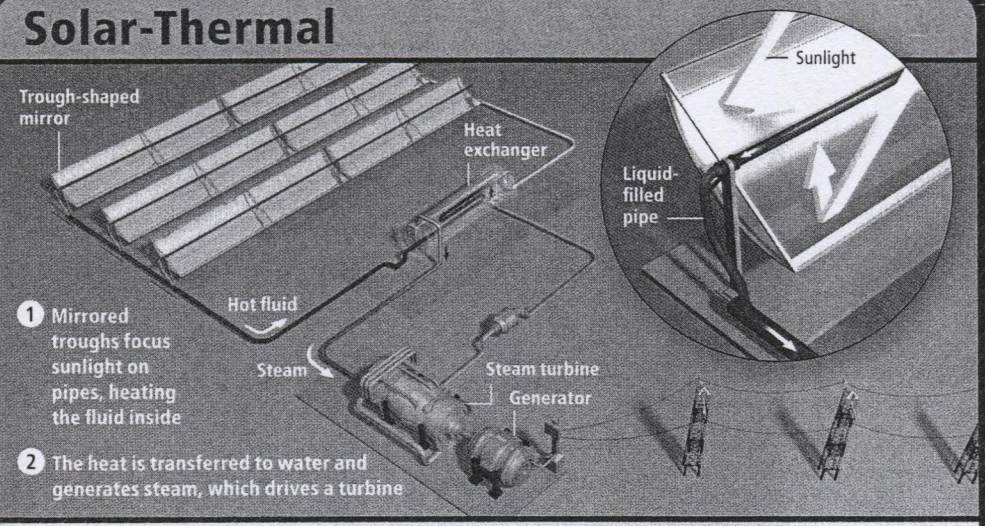
On the following pages is an overview of the elements of an energy system with a large contribution from renewables and the ways they might fit together.

JUSTIN SULLIVAN *Getty Images (electric car)*; LESTER LEFKOWITZ *(solar panels)*; SCOTT OLSON *Getty Images (ethanol sign)*; ARCTIC-IMAGES/CORBIS *(geothermal plant)*; GEORGE FREY *Getty Images (wind turbine)*

Generating Electric Power

No technology provides a one-size-

Solar-Thermal

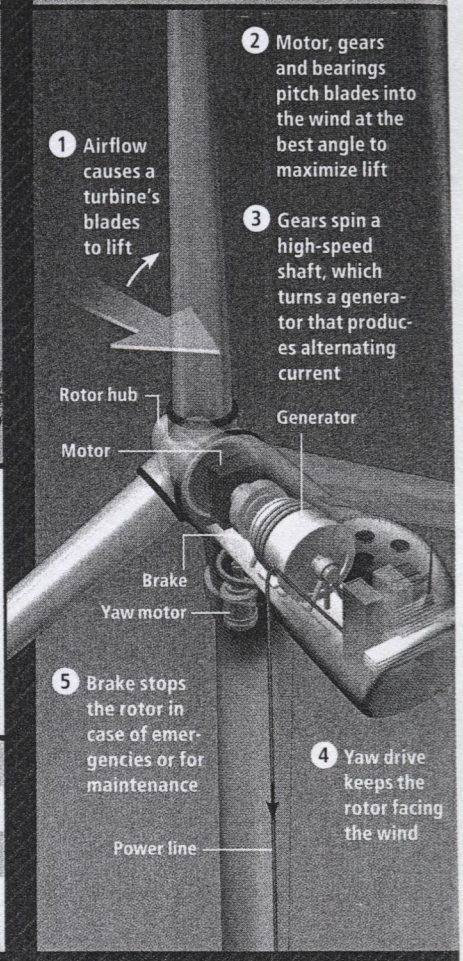


In solar-thermal, a trough-shaped mirror that tracks the sun over the course of the day focuses light to heat an oil- or water-based fluid in a black pipe. The pipe snakes over miles to a heat exchanger, which makes steam to drive a turbine. The system can be built as an adjunct to a natural gas–fired plant, so that gas can make steam during cloudy periods or after sunset. Future models may substitute molten sodium as the working fluid, which would allow higher temperatures without requiring higher pressures.

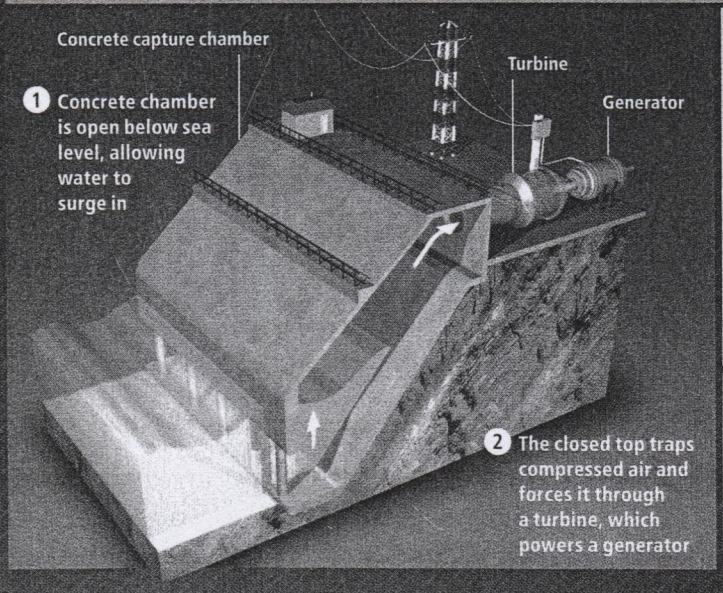
A variant is a "power tower," which looks a bit like a water tower but is filled with molten sodium and heated by a vast array of mirrors, some at a distance of a kilometer. The sodium can be connected to an insulated tank and can store enough heat to run around the clock or at least well into high-demand times.

STATUS	Trough systems are commercial; power towers have been demonstrated
PRICE	19.9–28.1 cents/kWh (for trough)
ADVANTAGES	May be the most amenable to storage of renewables
DRAWBACKS	Needs flat land; best resources may be distant from existing transmission; disturbs pristine desert environments; may require cooling water, which is hard to find in deserts, the sunniest areas

Wind



Ocean Wave Power



Hydroelectric has been developed as far as it can go, given environmental concerns about dams. But the Pacific Northwest coast could produce 40 to 70 kilowatts per meter, according to the Department of Energy. Harnessing ocean power is a long way behind wind, solar and geothermal, however. Inventors have been filing for wave-energy patents for two centuries.

One technique is to build a steel or concrete column, open to the ocean below the water line but closed at the top. The rise and fall with each wave alternately pressurizes and depressurizes the air at the top, which can drive a turbine; Wavegen in Scotland, partly owned by Siemens, the giant electrical company, recently opened a 100-kilowatt generator based on this system. Another design harnesses the energy of a rising and falling float.

STATUS	Demonstrated but not ready for prime time
PRICE	Too early to estimate
ADVANTAGES	Transmission lines are usually short
DRAWBACKS	Building durable structures in areas of strong surf is expensive

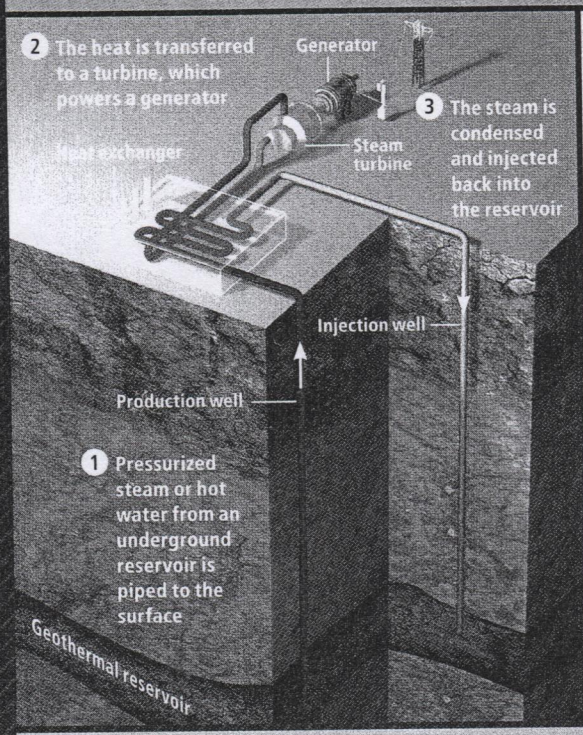
fits-all solution, but a combination can create a robust energy supply.

Wind is the most promising, most advanced—and perhaps most problematic of the renewable energy sources. In 2007 developers installed more than 5,000 megawatts in the U.S., raising the installed base by 46 percent. But the kilowatt-hour contribution was much smaller, because even on a good site wind produces only about 28 percent of the energy that would result from around-the-clock production. Worse, wind works best at night, when demand is low.

Technology is trimming costs, partly by making wind machines bigger. The latest are six megawatts, which would run several shopping centers. On a machine that big, each blade is about 65 meters, the approximate wingspan of a Boeing 747. New models are highly efficient, capturing about half the energy in the air that passes through them.

STATUS	Commercial; growing rapidly
PRICE	6.1–8.4 cents/kWh (but transmission can push those amounts higher)
ADVANTAGES	Offers greatest energy-producing potential; no need for cooling water
DRAWBACKS	Production correlates poorly with load; some object to the appearance and sound of the machines and transmission towers; threat to some birds and bats; may interfere with aerial surveillance radars; best sites are not near population centers

Geothermal

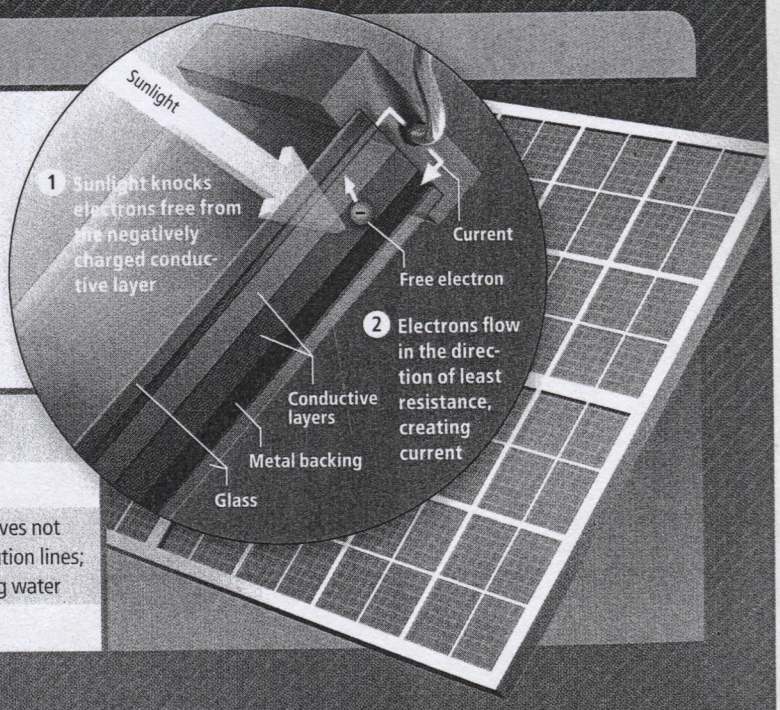


Unlike wind or solar, geothermal works on demand. "The heat in the earth is there; you can bank on it," says Steven Chu, director of Lawrence Berkeley National Laboratory and President Barack Obama's nominee for energy secretary. The plants generally run around the clock. Not every location has hot rock, but Hawaii generates a quarter of its energy that way and California, 6 percent. Geothermal installations use hot water that flows up by itself, but vast areas of the U.S. have "hot dry rock," proponents say, requiring only water injection through a deep well. Most systems use a heat exchanger to boil clean water for steam to spin a turbine.

STATUS	Commercial but small
PRICE	6.2–7.6 cents/kWh
ADVANTAGES	Supply is reliable enough to be used for base-load power
DRAWBACKS	The steam from underground water can have nasty components, which will rot heat exchangers and, if released, pollute the air; location is at the whim of nature and often not convenient to existing power lines

Solar-Photovoltaic

Two layers of semiconductor materials, one with extra electrons and the other with extra "holes," are sandwiched together in photovoltaic panels. When the material absorbs sunlight, excess electrons move from one layer to the other, creating an electric current. The effect was first observed 169 years ago, but scientists and engineers are still working to optimize it. The first practical use was in the space program, and cells are widely used off the grid but are not now competitive with fossil fuel or even other renewables on the grid. Photovoltaics can be incorporated into new construction, as roofing tiles or building facade materials, at lower cost.



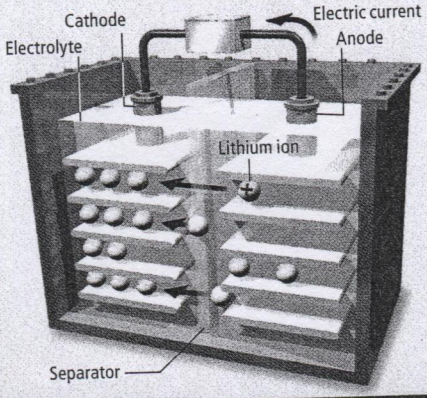
STATUS	Commercial but competitive in grid applications only when demanded by quota or heavily subsidized
PRICE	46.9–70.5 cents/kWh
ADVANTAGES	Can be deployed in electrically congested urban areas, where it saves not only the cost of generation but also the cost of laying new distribution lines; peak production matches peak load fairly well; no need for cooling water
DRAWBACKS	If you have to ask, you can't afford it; production is very small

Storing and Delivering Renewable Power

Intermittent sources of energy, such as wind and sun, require energy storage and delivery systems. Several candidates exist.

Automotive Batteries

Automakers want a lithium-ion battery that will endure 15 years and 5,000 charge cycles, far more than the familiar lithium ions in today's consumer devices. The goal is a price of $300 per usable kilowatt-hour of storage for a battery that would run a car for 40 miles, assuming a little more than three miles per kilowatt-hour. General Motors plans to market a plug-in hybrid in 2010; Ford's version is five years away. In this case, the voice in the car whining, "Are we there yet?" may not be the kid in the backseat; it may be the driver.

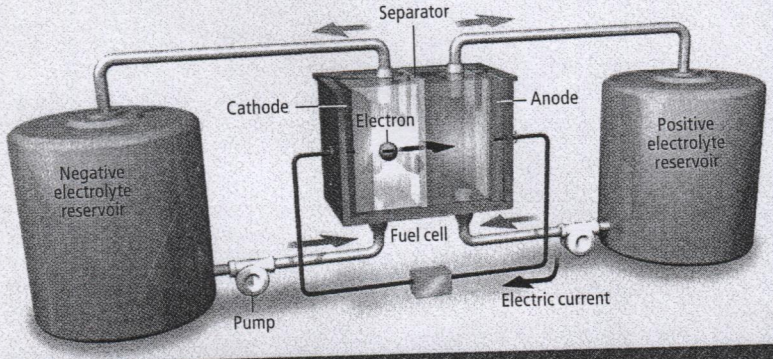


Fuel Cells

Electricity from any source, such as solar, wind and even coal, can be used to break up water molecules into their hydrogen and oxygen components in a device called an electrolyzer. The hydrogen can then be run through a fuel cell to make electricity. A downside of fuel cells, however, is that they have a capital cost in the thousands of dollars per kilowatt of capacity, and the round-trip efficiency through the electrolyzer to the fuel cell and then back into current is less than 50 percent—meaning that for every two kilowatt-hours put in the bank, only one comes back out again.

Stationary Batteries

A Vancouver-based company, VRB Power Systems, sells "flow batteries," with tanks to hold hundreds of gallons of electrolytes. Run in one direction, the system absorbs energy; in the other, it gives it back, in megawatt-hour quantities. It costs $500 to $600 to store a kilowatt-hour, and the round-trip efficiency is 65 to 75 percent—meaning the battery loses 25 to 35 percent of the electricity put into it. This system would raise the price of the solar kilowatt-hour by 50 percent or more.

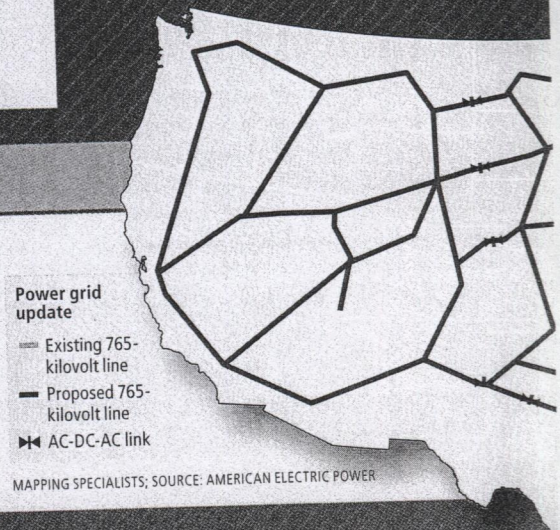


Compressed Air

The Alabama Energy Cooperative opened a compressed-air energy storage plant in 1991, using coal plants that ordinarily would be idle at night, to pump air into a hollowed-out salt dome at a pressure of more than 1,000 pounds per square inch. When extra power is needed in daytime, compressed air is inserted into a combustion turbine fired by natural gas. Ordinarily the turbine compresses its own air, and the most efficient generator today requires 6,000 British thermal units (Btu) of natural gas to produce a kilowatt-hour. Compressed air storage, in contrast, cuts natural gas use by one third.

Electricity Transmission

Intermittent sources are less troublesome if they feed a bigger grid; a region with 100 scattered installations of wind and solar could count on some average level of input. But the existing grid cannot handle bulk power transfers over huge distances. A solution could be a new high-voltage "backbone," akin to an interstate highway system for the grid, according to the Department of Energy last year. It would comprise about 19,000 miles of transmission, with 130-foot towers, at $2.6 million a mile. Voltage would be pushed up to 765,000 volts to reduce line losses. No new technology is involved, but the system requires two things that the U.S. does not now have: a national commitment to integrating the electricity system on a continental scale and about $60 billion to pay for it.



MAPPING SPECIALISTS; SOURCE: AMERICAN ELECTRIC POWER

Renewable Transportation Fuels

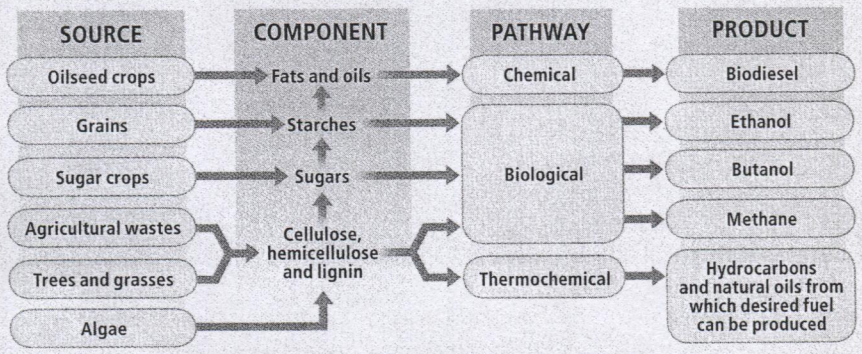
Three main pathways exist for making liquid transportation fuels from renewables. The first is simply to burn plant oils, most often soy or palm, in diesel engines. In the U.S., to be legal the oil must be converted to a chemical form called an ester. The process is simple, but the scale is limited, and the entire enterprise is caught up in the food-versus-fuel debate.

Equally simple is to let yeast digest sugars and produce alcohol, but that, likewise, is limited in scale and puts the corner filling station in competition with the supermarket for the output of the field.

Tremendous volumes of sugars, however, are tied up in nonfood crops and in the nonedible part of plants that are grown as food, such as wheat straw and corn stalks. This cellulosic material contains conventional six-carbon sugars as well as five-carbon sugars, which ordinary yeast does not like.

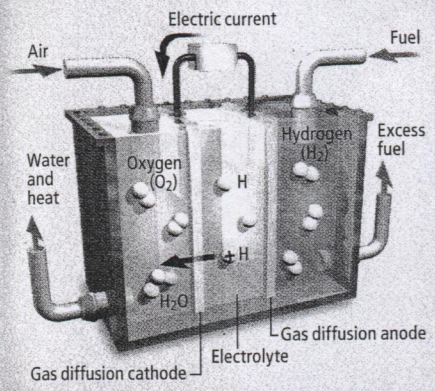
To unlock these sugars for the third pathway, some pilot-scale plants use steam or acids, or a combination. Another option is enzymes from gene-altered bacteria or fungi. To convert the sugars to liquid fuel, some use catalytic processes, and others turn to yeasts, often genetically altered as well. Some simply break down cellulosic material into a fuel gas of carbon monoxide and hydrogen, then re-form that into hydrocarbon molecules, such as ethanol, other alcohols or other liquids. Feedstocks include forest detritus, such as chips, bark and pinecones; paper and plastics from household garbage; and agricultural wastes.

Although all these methods have been shown to work on a lab or pilot scale, successful commercial operation remains elusive. Incentives and quotas are spurring many efforts, however.



SOURCE : "BIOFUELS FOR TRANSPORTATION," BY NAOMI PENA AND JOHN SHEEHAN, IN *CDM INVESTMENT NEWSLETTER*, NR. 3/2007

STATUS	Struggling toward commercial operation
PRICE	Not established; the target is uncertain because gasoline and diesel prices are so volatile
ADVANTAGES	Some biofuels are low- or zero-carbon; reduces reliance on overseas oil
DRAWBACKS	Some fuels put pressure on food prices; production of biofuels from corn requires copious amounts of fossil fuels, so total energy and carbon advantages are small; most biofuels are less energy-dense than gasoline, yielding fewer miles per gallon



Ice Storage

Ice Energy, a company based in California, sells equipment that yields 500-gallon blocks of ice at night, in building basements. Making ice at night is easier than doing so during the day, because the temperature of the outdoor air, to which the compressor must release the heat, is generally lower than it is earlier in the day. The resulting ice is used to cool the building during the daytime. The effect is to use energy produced at night, such as from wind power, to do work when it is needed during the daytime.

Matthew L. Wald is a reporter at the *New York Times*, where he has covered energy topics since 1979. He has written about oil refining, electricity production, electric and hybrid automobiles, and air pollution. Wald is currently based in Washington, D.C., where he also tracks transportation safety and other subjects. This article is his fourth for *Scientific American*.

MORE TO EXPLORE

Department of Energy scenario for meeting 20 percent of electric needs with wind by 2030: **www1.eere.energy.gov/windandhydro**

Hybrid power plant to be built in California that produces energy from solar power when it is available and natural gas when it is not: **www.inlandenergy.com**

Information on compressed-air energy storage: **www.solarfeeds.com/index.php?option=com_content&view=article&id=3256:compressed-air-energy-storage-further-along&catid=80:80&Itemid=173**

Renewable Fuels Association facts on cellulosic ethanol: **www.ethanolrfa.org/resource/cellulosic**