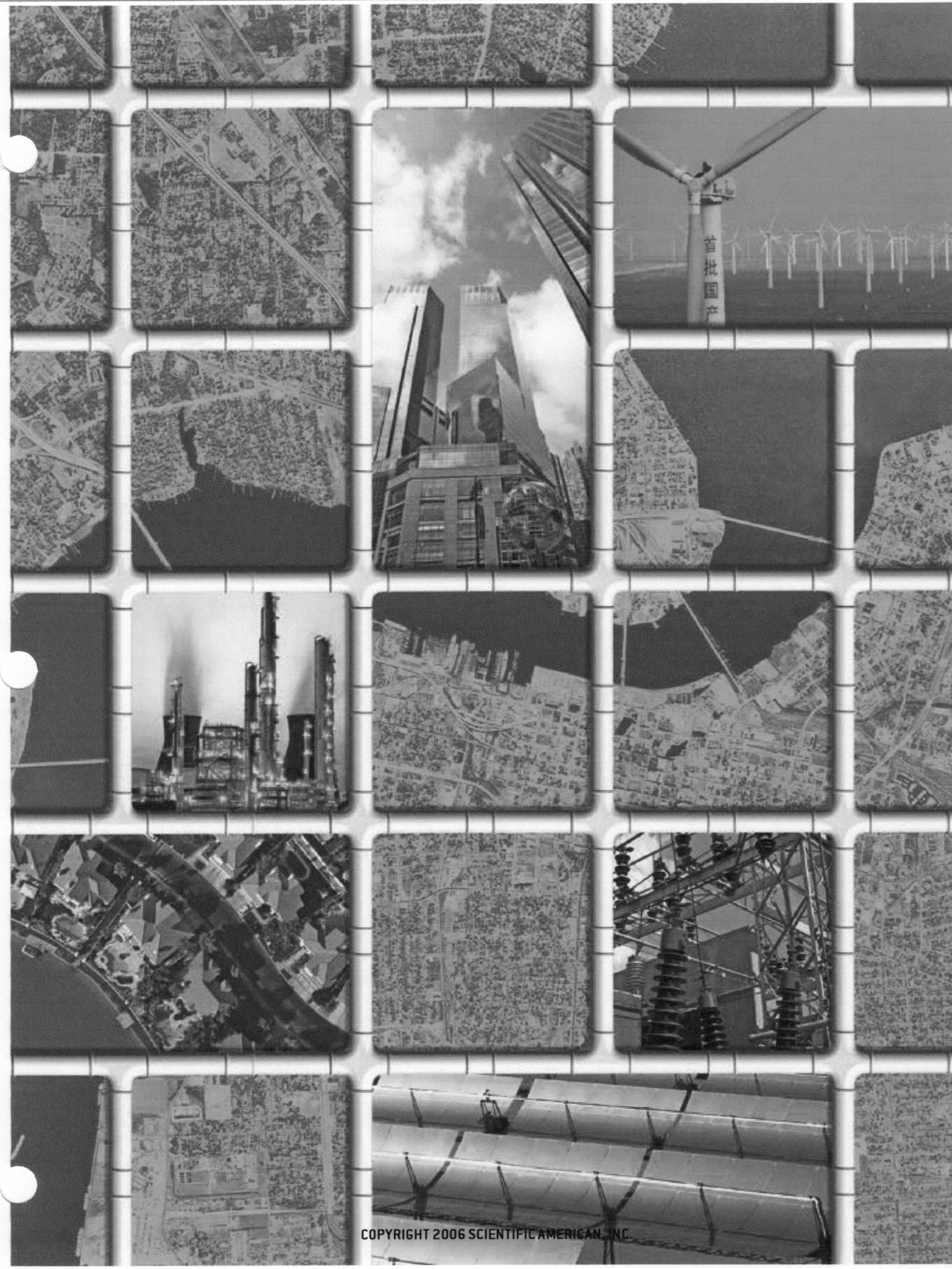
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A POWER GRID FOR THE HYDROGEN ECONOMY

Cryogenic, superconducting conduits could be connected into a "SuperGrid" that would simultaneously deliver electrical power and hydrogen fuel

By Paul M. Grant, Chauncey Starr and Thomas J. Overbye

On the afternoon of August 14, 2003, electricity failed to arrive in New York City, plunging the eight million inhabitants of the Big Apple—along with 40 million other people throughout the northeastern U.S. and Ontario—into a tense night of darkness. After one power plant in Ohio had shut down, elevated power loads overheated high-voltage lines, which sagged into trees and short-circuited. Like toppling dominoes, the failures cascaded through the electrical grid, knocking 265 power plants offline and darkening 24,000 square kilometers.

That incident—and an even more extensive blackout that affected 56 million people in Italy and Switzerland a month later—called attention to pervasive problems with modern civilization's vital equivalent of a biological circulatory system, its interconnected electrical networks. In North America the electrical grid has evolved in piecemeal fashion over the past 100 years. Today the more than $1-trillion infrastructure spans the continent with millions of kilometers of wire operating at up to 765,000 volts. Despite its importance, no single organization has control over the operation, maintenance or protection of the grid; the same is true in Europe. Dozens of utilities must cooperate even as they compete to generate and deliver, every second, exactly as much power as customers demand—and no more. The 2003 blackouts raised calls for greater government oversight and spurred the industry to move more quickly, through its IntelliGrid Consortium and the GridWise program of the U.S. Department of Energy, to create self-healing systems for the grid that may prevent some kinds of outages from cascading. But reliability is not the only challenge—and arguably not even the most important challenge—that the grid faces in the decades ahead.

A more fundamental limitation of the 20th-century grid is that it is poorly suited to handle two 21st-century trends: the relentless growth in demand for electrical energy and the coming transition from fossil-fueled power stations and vehicles to cleaner sources of electricity and transportation fuels. Utilities cannot simply pump more power through existing high-voltage lines by ramping up the voltages and currents. At about one million volts, the electric fields tear insulation off the wires, causing arcs and short circuits. And higher currents will heat the lines, which could then sag dangerously close to trees and structures.

It is not at all clear, moreover, how well today's infrastructure could support the rapid adoption of hybrid vehicles that draw on electricity or hydrogen for part of their power. And because the power system must continuously match electricity consumption with generation, it cannot easily accept a large increase in the unpredictable and intermittent power produced from renewable wind, ocean and solar resources.

A hydrogen-filled SuperGrid would serve not only as a conduit but also as a vast repository of energy.

We are part of a growing group of engineers and physicists who have begun developing designs for a new energy delivery system we call the Continental SuperGrid. We envision the SuperGrid evolving gradually alongside the current grid, strengthening its capacity and reliability. Over the course of decades, the SuperGrid would put in place the means to generate and deliver not only plentiful, reliable, inexpensive and "clean" electricity but also hydrogen for energy storage and personal transportation.

Engineering studies of the design have concluded that no further fundamental scientific discoveries are needed to realize this vision. Existing nuclear, hydrogen and superconducting technologies, supplemented by selected renewable energy, provide all the technical ingredients required to create a SuperGrid. Mustering the social and national resolve to create it may be a challenge, as will be some of the engineering. But the benefits would be considerable, too.

Superconducting lines, which transmit electricity with almost perfect efficiency, would allow distant generators to compensate for local outages. They would allow power plants in different climate regions to bolster those struggling to meet peak demand. And they would allow utilities to construct new generating stations on less controversial sites far from population centers.

SuperGrid connections to these new power plants would provide both a source of hydrogen and a way to distribute it widely, through pipes that surround and cool the superconducting wires. A hydrogen-filled SuperGrid would serve not only as a conduit but also as a vast repository of energy, establishing the buffer needed to enable much more extensive use of wind, solar and other renewable power sources.

Overview/A Continental SuperGrid

- As the 2003 blackouts in North America and Europe vividly testify, the current power grid is struggling to meet growing demand for electricity and the coming shift from fossil-fueled power and cars to cleaner sources of energy.
- For several years, engineers have been designing a new infrastructure that would enable cities to tap power efficiently from large nuclear and renewable energy plants in distant and remote locations.
- SuperCables would transmit extraordinarily high electrical current nearly resistance-free through superconducting wires. The conduits would also carry ultracold hydrogen as a liquid or high-pressure gas to factories, vehicle fueling stations, and perhaps one day even to home furnaces and boilers.

PRECEDING PAGES: SLIM FILMS; CORBIS (*background satellite image*); BOB SACHA *Corbis* (*wind power*); ALAN SCHEIN PHOTOGRAPHY *Corbis* (*office buildings*); PREMIUM STOCK/CORBIS (*power plant*); GEORGE STEINMETZ *Corbis* (*aerial view of houses*); CORBIS (*solar arrays and substation*); BMWAG, MÜNCHEN (*hydro car*); ZUMA PRESS (*clean vehicles*); AMERICAN SUPERCONDUCTOR, INC. (*superconducting cable*); ROBERT HARDING *World Imagery/Corbis* (*houses*)

And it would build the core infrastructure that is a prerequisite if rich economies are to move away from greenhouse-gas-emitting power plants and vehicles.

A New Grid for a New Era

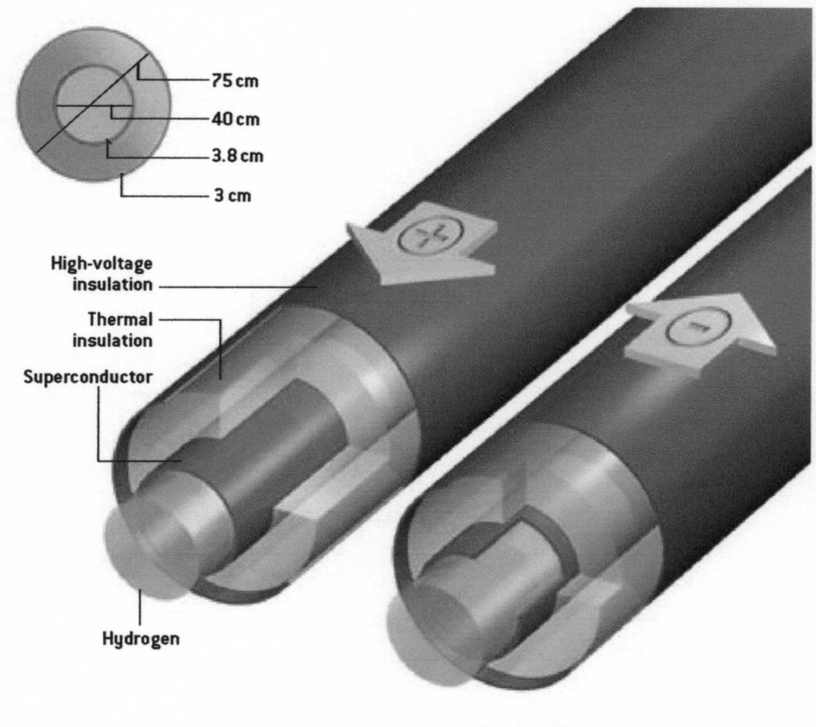
A CONTINENTAL SUPERGRID may sound like a futuristic idea, but the concept has a long history. In 1967 IBM physicists Richard L. Garwin and Juri Matisoo published a design for a 1,000-kilometer transmission cable made of niobium tin, which superconducts at high currents. Extraordinary amounts of direct current (DC) can pass resistance-free through such a superconductor when the metal is chilled by liquid helium to a few degrees above absolute zero. The scientists proposed a DC cable with two conductors (made of superconducting wire or tape) that together would carry 100 gigawatts—roughly the output of 50 nuclear power plants.

Garwin and Matisoo were exploring what might be possible, not what would be practical. It would not make sense to inject that much power into one point of the grid, and liquid helium is a cumbersome coolant. But their ideas inspired others. In the following decades, short superconducting cables were built and tested to carry alternating current (AC) in Brookhaven, N.Y., and near Graz, Austria, with the latter operating connected to the local grid for several years.

Ten years after the discovery of high-temperature superconductivity, a technical study by the Electric Power Research Institute (EPRI) concluded that with liquid nitrogen as a coolant, a five-gigawatt DC "electricity pipe" could compete economically with a gas pipeline or conventional overhead lines for transmission distances of 800 kilometers or more. Two of us (Grant and Starr) developed the idea further in papers that explored how ultracold hydrogen—either liquid or supercritical gas—might both chill the superconducting wires and deliver energy in chemical form within a continental-scale system. In 2002 and 2004 the third author (Overbye) organized workshops at which dozens of experts detailed a plan for a 100-meter pilot segment, precursor to a 50-kilometer intertie between existing regional grids.

SUPERCABLES

SuperCables could transport energy in both electrical and chemical form. Electricity would travel nearly resistance-free through pipes (*red*) made of a superconducting material. Chilled hydrogen flowing as a liquid (*blue*) inside the conductors would keep their temperature near absolute zero. A SuperCable with two conduits, each about a meter in diameter, could simultaneously transmit five gigawatts of electricity and 10 gigawatts of thermal power (*table*).



	Voltage/Temperature	Flow rate	Power delivered
DC circuit	+50,000 volts and −50,000 volts	50,000 amperes	5,000 megawatts electric
Liquid hydrogen	20 kelvins	0.6 cubic meter/ second in each pipe	10,000 megawatts thermal

It is important to develop prototypes soon, because existing electrical grids are increasingly reaching the point of maximum loading—and, as the blackouts indicate, occasionally exceeding it. As total generating capacity in the U.S. has risen by almost a quarter in the past five years, the high-voltage transmission grid has grown in size by just 3.3 percent. Yet society's appetite for energy continues to grow rapidly: the U.S. Energy Information Administration forecasts that by 2025 annual energy use in the U.S. will hit 134 trillion megajoules (127 quadrillion BTUs), over a quarter greater than it was in 2005.

The rising demand poses two problems: where to get this new energy and how to distribute it. Fossil fuels will probably still supply a large fraction of our energy 20 years from now. But global competition for limited petroleum and natural gas resources is intense, and even mild production shortages can send prices skyrocketing, as we have seen in the past few months. Concern

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