

SCIENTIFIC
AMERICAN

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THE ADVANCE OF TECHNOLOGY depends on many heroic efforts, not all in the laboratory. Scientists and engineers extend our understanding and control of the physical world, while industrialists and corporations mobilize their own forces to make innovations available and commentators and legislators shape the policies guiding how society uses technology. This new annual roundup, the SCIENTIFIC AMERICAN 50, honors four dozen individuals, teams and companies—selected by the editors for their recent contributions to 12 broad categories of technological endeavor—as well as a Research Leader and a Business Leader of the Year. Join us in celebrating their bright visions of the future.



STEPHEN GOFF, HUANMING YANG and JUN YU

Goff, Syngenta's Torrey Mesa Research Institute; Yang, Beijing Genomics Institute; and Yu, University of Washington Genome Center

Vision: Deciphering the genome of rice paves the way for breakthroughs in farming humankind's most important food staples.



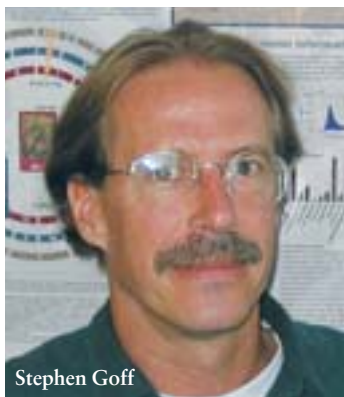
Cultivated rice

THE APRIL 5, 2002, ISSUE OF *SCIENCE* published two papers from independent laboratories that simultaneously reached a long-awaited goal: a map of the rice genome. The studies provided gene sequences—lists of genetic building blocks, called nucleotide bases, that make up an organism's chromosomes—for two types of rice, a crop that feeds more than half the world's population. One study, led by Huanming Yang and Jun Yu, unveiled a draft sequence for *indica*, a subspecies that is common in most of Asia. Another team, directed by Stephen Goff, published a similar report on *japonica*, usually grown in Japan. Together the investigations should lead to better strains of rice and benefits for other crops.

Both groups achieved their goals by leveraging a powerful combination of molecular biology and computer science called the whole-genome shotgun method. In most sequencing, scientists examine the DNA piece by piece, but the shotgun technique looks at the entire genome at once. Scientists break up the genome, sequence the overlapping pieces simultaneously, then use advanced computing to arrange the segments as they exist on the chromosomes. The technique's virtue is speed: genome-sequencing projects by other means can take years, but Yang and his colleagues, working around the clock, completed the sequencing in just 74 days.

Each of the rice studies predicts that its subspecies contains tens of thousands of genes, but no one knows exactly how many. Although the shotgun technique gives an approximate number, it can leave holes in the overall sequence. Goff estimated that *japonica* contains between 32,000 and 50,000 genes. Nevertheless, the shotgun method reveals important information. Yang and Yu's team, for instance, concluded that a rice gene creates only one protein, whereas a single human gene usually spawns several. This understanding is expected to make it easier to determine exactly what proteins these genomes make.

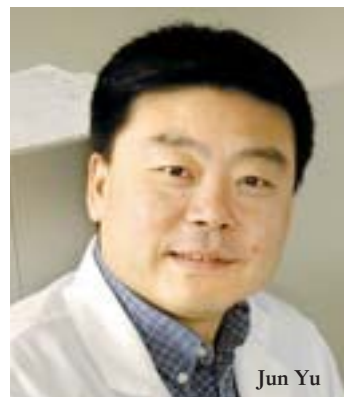
Knowing the sequences of rice species should also give scientists a good start on defining all grasses, which is the family of many grain crops, including wheat, corn, oats, sorghum and barley. Of all the world's agricultural land, 70 percent of the acres are planted in rice, wheat and corn. Because the rice sequence probably contains most of the same genes found in those other grasses, researchers anticipate that the rice knowledge will help advance the efforts on the more complex crops. Meanwhile, armed with the genome maps of Goff, Yang and Yu, scientists will be able to breed or engineer rice that resists disease, drought and pests.



Stephen Goff



Huanming Yang



Jun Yu

RIC ERGENBRIGHT Corbis (top); LISA MATTLE (bottom left); COURTESY OF HUANMING YANG (bottom center); COURTESY OF JUN YU (bottom right); MARK GILBERT (opposite page)

**GEOFFREY BALLARD**

Chairman, General Hydrogen

Vision: Hydrogen can replace gasoline as the automotive fuel of choice.

GEOFFREY BALLARD, A.K.A. MR. HYDROGEN, has done more than anyone to advance fuel cells. Like batteries, fuel cells cleanly convert chemical energy into electrical power. But they wring more power from their weight, in part because they don't have to store a key ingredient: oxygen from the air. Last year, having concluded that the greatest remaining impediment to fuel cells' widespread adoption was the lack of a system for distributing hydrogen fuel, Ballard co-founded General Hydrogen in Vancouver to solve the problem. The company has backing from the Canadian government and alliances with British Energy, General Motors and other corporations.

Ballard, 70, is a dual citizen of Canada and the U.S. He trained as a geophysicist and worked for the oil industry, the U.S. military and the then newly founded Department of Energy, where he studied energy conservation. He soon judged that conservation alone could not free up sufficient energy for developing countries and in 1975 went into business for himself.

Ballard turned a former motel in Arizona into a laboratory to work on his first project, lithium batteries. That enterprise never paid off. Nevertheless, Ballard Power Systems, which he founded in 1979, went on to make inexpensive hydrogen-consuming fuel cells that replaced liquid and heated ceramic electrolytes with a thin plastic barrier, called a proton exchange membrane (PEM). The concept had been worked on in the mid-1960s by General Electric for NASA's Gemini program, only to be supplanted later. Ballard revived the approach in the 1980s, after the patents had expired, and rendered it cost-effective through discoveries made by him and others.

In 1993 Ballard demonstrated PEM by using it to power a 30-foot city bus in Vancouver, dubbed the "Ballard Bus." Four years later Daimler-Benz (now DaimlerChrysler) and Ford Motor Company, themselves developers of fuel cells, bought equity stakes in the company. Ballard, finding he had less interest in running companies than in starting them, left in 1998. He subsequently co-founded General Hydrogen.

General Hydrogen is developing ways to sidestep the chicken-and-egg problem of a hydrogen-based automotive economy: no one wants to make cars without readily available fuel, and no one wants to distribute fuel without a large population of cars. The company has not unveiled its entire strategy; so far its main product is a high-pressure gas canister to store fuel in the vehicle, a critical link in the chain of supply.

When Ballard first plunged into fuel-cell research, he hoped to save cities from smog. Tightening auto-emissions standards soon lent support to Ballard's efforts. Now another issue he could not have foreseen—the fight against global warming—has further strengthened the case for his hydrogen economy. The question is, Where will all the energy come from to manufacture that hydrogen? "Within the scope of today's technology, nuclear fission is the only viable, clean source of large quantities of energy," Ballard said recently in Montreal. Improvements in fission safety have been achieved, he argues, and the risks that remain compare favorably with those inherent in fossil-fuel sources.



Geoffrey Ballard



AGRICULTURE

RESEARCH LEADER

ALLISON A. SNOW

Professor of evolution, ecology and organismal biology, Ohio State University

Vision: The potential of genetically engineered crops to pass traits to weeds must be understood.

SCIENTISTS CAN ENHANCE MODERN CROPS by using advanced molecular biology to add genes that confer beneficial traits, such as drought tolerance and pest resistance. Unfortunately, as Allison Snow has shown, these transgenic crops can also sometimes crossbreed with related weeds—those sharing the same genus—that may surround a field crop, giving the hybrid weeds the robust traits, too. This transference might create a powerful weed that is harder to control.



Allison A. Snow

In 2001 Snow and her colleagues presented their findings from a series of experiments at the University of Michigan Biological Station. They worked with two kinds of radish: an edible one and its wild, weedy relative. Under ordinary circumstances, the weedy relative is the growth champion among the two species and easily wins any battle between them to capture acreage. Snow and her team crossed the two strains, developing a hybrid similar to what might be created in the field between a crop and a related weed; they then tested the productivity of the original weed and the weedy hybrid in large field tests.

The results dispel some folklore surrounding the safety of genetic engineering for crops. Supposedly, hybrid plants reproduce less and eventually die out, so if a trait were to pass from a genetically engineered crop to a nearby relative, the resulting hybrid weed would not survive very long. Yet Snow watched her hybrid wild radishes grow and reproduce through six generations. Even more dangerous, the reproductive capabilities of the hybrids improved in the second generation over the first. Moreover, after a couple of generations, traits from the edible radish, including the color of its flowers, started showing up in the hybrid, as the genes for color began to express themselves more strongly. If the crop radish can pass flower color to its weedy relative, it could also pass other traits, such as ones added to the crop through genetic engineering.

Hybrid superweeds could create real trouble for farmers. The weedy relative of the radish, which is superior in reproduction, might become even more aggressive if it acquired potent new traits from a crop with modified chromosomes. Many crops could face similar challenges: carrots, oilseed rape, rice, sorghum, squash, sunflowers and others already compete with natural weedy relatives. Weedy hybrids could grow too strong to be held back by the herbicides that currently minimize their invasion of agricultural fields. And it could happen fast. As Snow's diligent research shows, the hybrids can appear in a single season and evolve quickly into more aggressive invaders.

BUSINESS LEADER

STEVEN BURRILL MANAGES more than \$100 million in two agricultural biotechnology investment funds, AgBio Capital Funds I and II. But his reputation as a spokesperson for life

sciences and technology industries is what makes him a highly regarded voice in the investment community. The funds invest in a handful of companies—such as Aventis CropScience and Bayer—that steer clear of controversial genetically modified organisms. Burrill also forges deals among companies that are creating hardier animal breeds for agriculture. In May, Burrill guided Pyx-

G. STEVEN BURRILL

Chief executive officer, Burrill & Company

Vision: Ag-biotech is promising and deserves prudent investment.

is Genomics to a \$17.5-million collaboration with Genome Canada to explore the genetics of infectious diseases in cattle and poultry. Pyxis uses DNA microarrays to

identify genetically superior animals that can be bred for resistance to food-borne illnesses or for other desirable traits. To keep investors and managers up-to-date, he has convened many meetings, including the Life Sciences Partnering Meeting. In addition, he writes an annual report—the most recent is “Bio 2002”—that some call the bible of biotechnology.



G. Steven Burrill

COMPANY

PRODIGENE

Vision: Transgenic corn can be used as a chemical factory to produce proteins for an edible AIDS vaccine and other pharmaceuticals.

THIS YEAR PRODIGENE in College Station, Tex., showed that its genetically modified corn can produce compounds for a vaccine that might fight AIDS. The corn makes a protein called gp120, which is situated on the surface of HIV. Investigators hope that ingesting small amounts of the protein could trigger the production of antibodies against HIV, helping to defeat the virus and beat any future HIV infection. ProdiGene is now conducting tests to see whether the protein triggers a useful immune response when ingested by animals. The transgenic corn could also make large quantities of gp120 for HIV research. This and other proteins from ProdiGene will be some of the first industrial-scale products from a transgenic plant, and they could be developed into pharmaceuticals or industrial proteins. For example, ProdiGene recently used its corn to produce trypsin, an enzyme used in pharmaceutical manufacturing and other industrial processing; it should be available in 2003.



Altered corn

POLICY LEADER

SANDRA L. POSTEL

Director, Global Water Policy Project

Vision: Sweeping changes in farming and consumer habits could preserve the world's dwindling supplies of freshwater.

SANDRA POSTEL SEES the decreasing supply of freshwater as the planet's greatest environmental and social challenge. Her private research group, headquartered in Amherst, Mass., helps people around the world get as much benefit as possible from every drop of water. Because agricultural irrigation uses two thirds of all the water taken from rivers, lakes and aquifers, it draws the lion's share of Postel's attention. She advocates a host of improvements for farming, including more efficient irrigation systems and the recycling of wastewater for irrigation. She encourages homeowners to landscape using native plants, which consume less water than the standard, carpetlike grass lawn. Postel also promotes a vegetarian diet, because sustaining high-meat diets such as those in the U.S. requires extensive agricultural water use. Postel's ideas are capturing worldwide attention. For example, the Sopris Foundation invited her to speak as a leading authority on global freshwater issues at its 2002 State of the World Conference.



Sandra L. Postel



CHEMICALS AND MATERIALS

RESEARCH LEADER

ANTHOULA LAZARIS and COSTAS KARATZAS

Lazaris, senior scientist, and Karatzas, senior vice president for R&D, Nexia Biotechnologies

Vision: Natural, superstrong materials and other products can be manufactured through the genetic engineering of milk proteins.

HIGH ON THE WISH LIST of everyone involved in biomimetics, the field that mimics the materials made by living things, has been a means of mass-producing spider silk. In the past year this milestone was reached by Anthoula Lazaris and Costas Karatzas, a husband-and-wife team, and their colleagues at Nexia Biotechnologies in Montreal. The achievement was striking for a company employing only 100 people, given that it beat mighty DuPont, which had spent 10 years chasing the same goal.

Spider dragline silk is lighter, much tougher and more flexible than an equivalent volume of DuPont's Kevlar aramid fiber—

the strongest synthetic fiber on the market. The silk should make possible lightweight body armor that can stop a bullet without weighing down a soldier. Small wonder, then, that after scientists in 1990 identified the two spider genes that make the dragline silk protein, it was military researchers who first spliced them into bacteria to try to manufacture the stuff. Bacteria, however, turned out truncated proteins that lacked toughness. Nexia decided to tackle the problem because of the company's expertise in just the right areas: mammalian genetic engineering and large-molecule biosynthesis.

Lazaris and Karatzas were at the technical heart of the effort, as they are for everything Nexia does, says founder and chairman Jeffrey D. Turner. The two employees have been with Turner since he met them when he was a biology professor at McGill University and they were finishing doctorates in molecular biology there. "Anthoula has a firm grasp of gene expression," Turner notes, "and Costas has a strong background in using that to make things, especially large proteins."

Lazaris and Karatzas began by proving that they could get silk from mammalian cells, splicing the spider genes into cow and hamster cells and culturing them until they could draw off enough protein to work with. Then collaborators at the U.S. Army Soldier and Biological Chemical Command in Natick, Mass., used syringes to squeeze out fiber

a bit finer than a human hair. The fiber turned out more elastic than, but wider and not quite as strong as, natural dragline silk. The next step was to splice the genes into mammary cells in Nexia's patented breed of fast-growing, early-lactating goats. Goat mammary glands, standing in for a spider's spinnerets, can manufacture the silk along with the milk and secrete tiny silk strands from the animal's body by the bucketful. The polymer strands would have to be extracted from the milk and woven into thread. A few silk-secreting goats have already been born, and the company is now breeding them with hundreds of standard animals on two farms in Canada and the U.S. Beyond flak jackets for the military, Lazaris and Karatzas hope to see their fibers developed as microsutures, artificial ligaments, tennis racket strings and other products demanding advanced materials.



Anthoula Lazaris and Costas Karatzas



Randy Howard

BUSINESS LEADER

LAST YEAR Randy Howard's company began making plastic not from petroleum but from corn, marking the industry's first foray into renewable products. Howard emphasizes that his firm, a joint venture in Minnetonka, Minn., of Dow Chemical and private grain trader Cargill, sells its biologically based, compostable plastic on performance alone. That is quite a feat in a commodity market that otherwise has not provided the profit margins that biomaterials have enjoyed in pharmaceuticals and other health-related industries. The plastic, called polylactide, has so far

RANDY HOWARD

President and CEO, Cargill Dow

Vision: "Green" plastics can compete economically with more polluting alternatives.

found its way into retail food containers, soft-drink cups and bedding. More products will emerge as manufacturing ramps up at a new factory in Blair, Neb., in the heart of corn country. At capacity it will consume 40,000 bushels of corn a day, but eventually some of the fermentation feedstock will come from an even more ecofriendly source: comstalks and other crop stubble.

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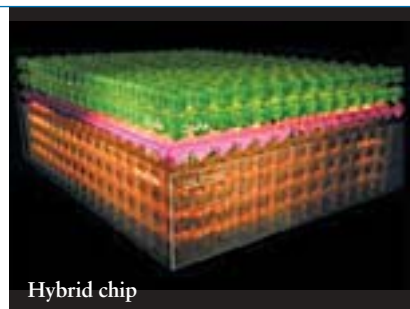
COMPANY

MOTOROLA

Vision: Varieties of semiconductors could be combined affordably on a single, superior integrated-circuit chip.

IN THE PAST TWO YEARS Motorola has aggressively developed a novel process for layering gallium arsenide onto silicon microchips. That goal had eluded a generation of engineers in the 1980s, most of whom had given up by the time Motorola's Jamal Ramdani achieved it in 1999, by inserting a buffer layer of strontium titanate between the clashing crystals. The forced marriage promises to integrate heretofore incompatible materials, leading to chips that can handle optical signals and electronics that are

much faster as well as far cheaper than silicon circuits. Other compound semiconducting materials should also yield to this strategy. Among the tempting applications are the use of one chip to do the work of many, particularly in wireless products. Motorola has launched a crash program to develop the chips in a wholly owned subsidiary, Thoughtbeam, in Austin, Tex. It has already generated hundreds of patents and produced prototype chips for cell phones.



Hybrid chip

POLICY LEADER

JON S. CORZINE

U.S. Senator of New Jersey

Vision: Better federal and public oversight can fortify chemical plants against terrorists and accidents.

AFTER THE SEPTEMBER 11 ATTACKS, Senator Jon Corzine submitted a bill to improve protection against terrorist acts and industrial accidents at chemical plants. According to an Environmental Protection Agency study, about one in 10 chemical plants handles toxic materials in quantities sufficient to endanger the surrounding population in the event of an uncontrolled release. The study cites two facilities in heavily populated areas in Corzine's state—a factory in East Rutherford that handles chlorine and another in South Keamey that works with sulfur dioxide. Corzine's bill would require the Justice Department and the EPA to identify such plants and ensure that they cut their use of dangerous materials while improving their security measures. Corzine, a freshman senator and former investment banker, has also opposed the Bush administration's efforts to keep secret reports such as the EPA's that identify potential disaster scenarios, arguing that terrorists who want a list of inviting targets can simply consult a telephone book.



Jon S. Corzine

CARGILL DOW (top); MOTOROLA (middle); CHARLES REX ARBOGAST AP Photo (bottom)

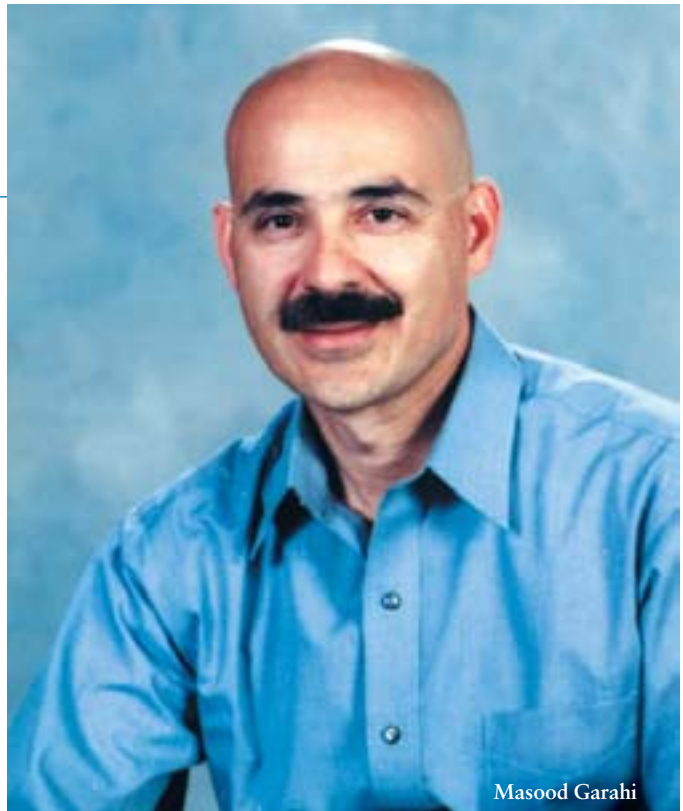


BUSINESS LEADER

MASOOD GARAHİ

Chairman and CEO, MeshNetworks

Vision: Broadband wireless networks can arise and thrive without massive investment in infrastructure.



WHEN YOUR CELLULAR PHONE cuts out at a crucial point in a conversation, blame it on the shortage of base stations, the relay transceivers on hilltops and buildings that track phones in their vicinity and hand them off to neighboring stations as you move about. Base stations cost a lot of money, which is why engineers look for ways to make the most of those already erected. Masood Garahi's company may have a solution. In June, MeshNetworks in Maitland, Fla., released for field testing the first transceiver chips designed to establish so-called ad hoc wireless networks. The chips incorporate proprietary software and protocols that enable handheld devices to route calls to one another, turning them into a temporary "mesh" network. Garahi maintains that the technology could be cheaper and more quickly put into practice than the long-proposed solution, a standard known as 3G, whose reliance on plentiful base stations has slowed its implementation.

In a mesh network—itsself an emerging technology—signals from mobile devices hop along a string of small antennas on, say, telephone poles to a base station, which communicates with the Internet and wired telephone systems. In Garahi's basic scheme, the handheld devices themselves do the job of those antennas. In his advanced scheme, they calculate the best route for a signal, acting as full-fledged routers. In both cases, the cell phone needs a new chip, and Garahi's is it.

Garahi sent his first transceivers into field tests in June, in Delphi Corporation's Japanese networks. There they fit into mobile phones, PDAs and laptops that seek out similarly equipped neighbors, start up two-way communication and then link with other such pairs to form an ad hoc network. If one of the devices can reach a base station, then the entire network has access. Yet even if no base station lies within range, the devices can at least talk to one another, eliminating dropped calls.

Application of this kind of peer-to-peer networking is perhaps best known from Napster's music-swapping service on the Internet. Garahi has argued recently that music swapping will eventually return, most likely among wireless networks. Any group of drivers idling in a traffic jam, for example, could share music files among themselves.

Mesh networks hark back to work at the Defense Advanced Research Projects Agency, which wanted to let soldiers quickly set up communications systems that would function even if parts were destroyed by enemy action. MeshNetworks, which Garahi helped to found in January 2000, licensed a related patent and did substantial development work. Previously, as chief technology officer at Skytel, Garahi led the development of the first two-way paging system.

COMPANY

XM SATELLITE RADIO

Vision: Satellite-based radio can provide CD-quality audio entertainment coast to coast without the homogeneous framework of commercial formats.

LAST YEAR XM SATELLITE RADIO in Washington, D.C., launched the first satellite service to provide radio airplay to the entire contiguous U.S. XM's two satellites, dubbed Rock and Roll, hover in geosynchronous orbit and beam down 100 channels of crystal-clear music, news and talk—far more variety than is available in a typical local market. Some 140,000

subscribers have paid \$200 for a radio set—primarily designed for automobiles—and a \$10 monthly subscription. More patrons are expected this fall when General Motors, which owns 22 percent of XM, begins selling 25 models that carry the radio as standard or optional equipment. Honda is also an investor. XM says it will turn profitable when it reaches four million subscribers, a daunting number given the competition recently offered by the even younger Sirius Satellite Radio, which has deals with Ford, Daimler-Chrysler and BMW. Still, independent estimates put the eventual market in the tens of millions.



Launch of XM satellite

RESEARCH LEADER



Marc Goldberg

TO ENSURE A QUALITY CONNECTION to all mobile users in its area, a broadcasting antenna may need such a strong signal that it interferes with neighboring antennas. Why not therefore trade the blunderbuss for a rifle, called an adaptive antenna, that would train a separate beam on each user, providing an even better connection and minimizing interference? The idea has many fathers, but Marc Goldberg, an electrical engineer and a founder of ArrayComm in San Jose, Calif., is one of the most successful at realizing it. Goldberg's algorithm measures all arriving signals, including late-arriving echoes, to infer a wireless device's position and then electronically manipulates the transmitted beam to converge there. Recent trials in Asian countries show that a base station with such "spatial channels" can serve 10 times as many customers as it could by simply broadcasting. In combination with mesh networks, smart antennas could postpone a bandwidth shortage that experts say will soon confront mobile communications.

MARC GOLDBURG

Chief technical officer, ArrayComm

Vision: Base stations can beam focused signals directly at mobile devices to improve and expand wireless services.

POLICY LEADER

LAWRENCE LESSIG SAYS that intellectual-property rights on the Internet have been defined in ways that favor corporate interests at the expense of the common good. He says certain Internet regulations are excessive and discourage innovation, an argument he made persuasively in his 2001 book, *The Future of Ideas* (Random House). Lessig, a former clerk to Supreme Court Justice Antonin Scalia, has no objection to intellectual-property rights or copyrights in general, but he insists that these laws were never intended, and should not be used, to reward innovators but rather to create incentives for people to innovate. He maintains that the recent 20-year extension of the Disney Corporation's copyright on Mickey Mouse fails that test because the cartoon's creators are dead and thus beyond all incentives. He has argued the point on the highest level, when the U.S. Supreme Court recently heard *Eldred v. Ashcroft*, which challenged the extension. The case has proved to be the most newsworthy copyright hearing in many years.

LAWRENCE LESSIG

Professor of law, Stanford University Law School, and founder of its Center for Internet and Society

Vision: Intellectual-property rights should not be used to stifle innovation.



Lawrence Lessig

SEA LAUNCH/AP PHOTO (top); ARRAYCOMM, INC. (middle); ELENA DORFMAN (bottom)



COMPUTING

BUSINESS LEADER



Paul Horn

PAUL HORN

Director, IBM Research

Vision: Computer systems should function like the human autonomic nervous system, taking care of themselves without coddling or supervision.

AT THE AGENDA 2002 CONFERENCE in October 2001, Paul Horn presented a self-described manifesto that challenged the computer industry to move toward “autonomic computing.” As systems become ever larger and more complex, Horn observed, the cost of their construction is increasingly dwarfed by the cost of keeping them running. Indeed, a study of computer installations at various institutions published in March by the University of California at Berkeley found that labor costs typically outstrip equipment costs by a factor of three to 18, depending on the type of system. And one third to one half of the total budget for such installations is spent preventing or recovering from crashes.

Developed under Horn’s direction, the IBM manifesto describes a vision in which major computer systems function less like confusing, maintenance-intensive agglomerations and more like the human autonomic nervous system. Horn notes that autonomic systems have eight defining characteristics that computer systems should exhibit. They should be aware of their own bound-

aries and be able to negotiate with other systems for access to resources. They should communicate using open standards, so the computing world isn’t divided into proprietary and incompatible fiefdoms. They ought to adapt to environmental changes, such as updated software or new equipment added to networks. They should monitor their own health, noting when performance falls and seeking ways to restore it. They should use active defense mechanisms to prevent malicious or accidental damage and be capable of repairing most malfunctions. Finally, and most ambitiously, to be more responsive and comprehensible, systems should anticipate users’ actions—rebooking a canceled flight, for example, or stopping an unbalanced assembly line.

IBM has since reorganized much of its research agenda around Horn’s vision. Horn saw to it that 75,000 copies of his manifesto were delivered to opinion leaders in academia and industry. He has also organized workshops and spoken at other conferences to encourage a more open and collaborative approach to long-term research. As a result, even though not everyone in the field agrees with its details, the manifesto has helped redirect the goals of the computer science community. At Hewlett-Packard, engineers are now focusing on “planetary” computing; at Microsoft, “trustworthy” computing; at Stanford University, “recovery-oriented” computing. No longer is higher performance the only goal.

Already one early IBM Research effort, Project eLiza, has been incorporated into all the company’s server products, making them easier to manage. Blue Gene, a supercomputer under construction, uses a “self-healing” cellular architecture that can detect failed processors and work around them. Truly autonomic systems are still years away. But at least now the software industry giants have taken a hard look at their products, confessed their flaws and vowed to do better.

POLICY LEADER

ANN BEESON HAS LED the ACLU's Technology and Liberty program to several signal court victories in the past year. Beeson and other ACLU attorneys challenged the Children's Internet Protection Act (CIPA), a law passed in 2000 that would force libraries to install "content filtering" software on all public Internet terminals. Studies have shown that existing censorship software cannot accurately distinguish pornographic sites from those that are useful and appropriate for children and other library visitors. Beeson also argued against the Child Online Protection Act (COPA), an older but similar law, before the U.S. Supreme Court last November. In May a federal appeals court ruled in favor of the ACLU and repealed the sections of the CIPA law that applied to libraries. The same month the Supreme Court blocked the enforcement of the COPA law.

ANN BEESON

Staff counsel, American Civil Liberties Union

Vision: People should be free to communicate, online and in all media, without fear of censorship.



Ann Beeson

COMPANY

MATRIX SEMICONDUCTOR

Vision: Integrating circuits vertically as well as horizontally will extend the semiconductor industry's fantastic rate of progress.

MOORE'S LAW—the steady growth in silicon-based microchip complexity on which the information technology industry depends—is approaching fundamental physical limits set by quantum mechanics. In late 2001 and early 2002 engineers at Matrix in Santa Clara, Calif., solved many long-standing technical problems that

had prevented the semiconductor industry from taking the next logical step forward: laying out and connecting circuit elements not just within a silicon substrate but also vertically in multiple silicon layers. The company's innovations promise in the short term to make solid-state digital recording media cheaper than photographic film and magnetic tape. In the long term, the expansion of silicon photolithography in the vertical dimension could accelerate Moore's Law and add years to its reign. Thomson Multimedia is incorporating Matrix's 3-D chips into digital audio and video storage cards for release next year.

RESEARCH LEADER



John Kubiawicz

COMPUTER SCIENTIST John Kubiawicz is chief architect of the innovative OceanStore system. OceanStore would provide a secure storage space in which millions or even billions of users could share countless gigabytes of digital data. Kubiawicz's team released prototype software for one part of the system in April and is now testing other components. Data deposited in OceanStore would be split into fragments, and multiple copies of each fragment would be placed on myriad computer servers and desktop machines around the world. The "grid computing" system can reconstruct files from just a fraction of the fragments and regenerate fragments as needed. Data would thus be protected against tampering and accidental damage for generations. Unlike the finicky servers available today, OceanStore would be largely self-maintaining, a crucial feature in an Internet-scale operating system. Kubiawicz sees OceanStore as part of a greater long-term agenda to build a global-scale operating system that combines the processing power and data storage capacities of millions of separate machines.

JOHN KUBIATOWICZ

Assistant professor of computer science, University of California, Berkeley

Vision: An Internet-scale "grid computing" system could knit together the processing and storage capabilities of millions of independent computers.

DECLAN McCULLAGH (top); ANTHONY JOSEPH (bottom)



DEFENSE

RESEARCH LEADER

JOAQUIN H. CASTRO

Manager of hypersonic programs, Pratt & Whitney Space Propulsion

Vision: Scramjets can propel aircraft and spacecraft at hypersonic speeds, cutting transit times significantly.



Joaquín H. Castro

THE DEVELOPMENT OF HYPERSONIC FLIGHT rocketed past a key milestone last year when engineers from Pratt & Whitney in West Palm Beach, Fla., and the U.S. Air Force successfully operated a powerful propulsion technology called a supersonic-combustion ramjet—"scramjet"—in a high-speed wind tunnel. Scramjet-engine technology has been investigated for nearly half a century because it could enable new generations of ultrahigh-performance aerospace vehicles. These include high-velocity missiles, strike or reconnaissance aircraft, and even space planes that could provide routine, affordable access to low-earth orbit.

A crack research team assembled and led by Joaquín Castro designed and built the functional scramjet prototype. The pioneering work was conducted under contract to the Air Force Research Laboratory as part of its \$80-million Propulsion Directorate's Hypersonic Technology (HyTech) program to demonstrate hydrocarbon-fueled scramjet engines. The open-ended HyTech project began in 1995 and should conclude in several years.

A variation of ramjet propulsion technology, a scramjet engine can start up only when the vehicle is already traveling at high speed. As forward progress rams intake air into the engine chamber, the air is compressed while fuel is injected into it. The resulting mixture ignites and expands out the exhaust nozzle at supersonic velocities. In terms of engineering difficulty, this accomplishment is equivalent to lighting a match in a hurricane.

After meticulous preparation, Castro's copper bench model produced positive net thrust while burning conventional fossil-based fuel in Mach 4.5 and 6.5 conditions. During previous attempts, researchers could not determine whether the power plants actually generated thrust. In addition, earlier scramjets ran on volatile, difficult-to-handle hydrogen rather than on traditional hydrocarbon fuels, for which a supply infrastructure already exists. Castro's project helps to prove that scramjets can be viable systems.

Although a scramjet is mechanically simple, the supersonic airflows inside it are extraordinarily complex; simulation requires sophisticated computer models. To improve the mixing of fuel and air and the system's overall performance, Castro's HyTech engineers minimized physical intrusions that could impede smooth passage through the flow path. The team also developed fuel-cooled engine structures in which standard JP-7 fuel removed heat from the combustion chamber while simultaneously being warmed and partially broken down before being set alight.

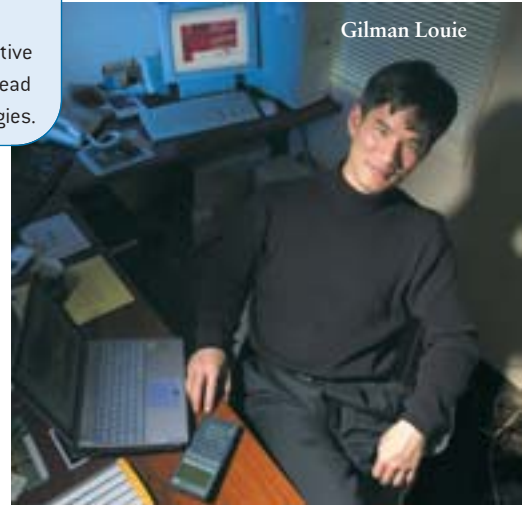
Castro and his development group are now finalizing the design of a forthcoming flight-weight test engine for ground demonstrations. Using this full-size device, the Pratt & Whitney researchers will evaluate performance, operability and structural integrity in a supersonic wind tunnel. Developers must meet strict size and weight requirements to create a flight-worthy scramjet prototype. Following successful ground trials, industry and government scientists and engineers will begin extending the advanced scramjet-engine cycle to future hypersonic vehicle designs, such as the NASA-USAF X-43C space plane.

BUSINESS LEADER

GILMAN LOUIE

President and CEO, In-Q-Tel

Vision: The CIA can harness the innovative power of free enterprise to stay ahead in intelligence-gathering technologies.



Gilman Louie

FOR NEARLY 60 YEARS, the U.S. Central Intelligence Agency developed advanced technologies to support its critical missions by establishing classified “skunkworks” operations in which a group of researchers or a quasi-company was set up to build specific products. Unfortunately, the blistering pace of innovation today has made it difficult for America’s spy organization to access and absorb the latest information technologies. In late 1999 the CIA decided to address this problem by chartering Arlington, Va.–based In-Q-Tel as a private not-for-profit venture-capital fund dedicated to identifying and delivering next-generation tools for such tasks as knowledge management and remote sensing. Led by Gilman Louie, an interactive-games business pioneer, the “venture catalyst” firm is investing about \$30 million a year in new technical approaches to problems facing an agency inundated daily with massive amounts of data. “Our mission is to go after technologies that are going to get to market anyway,” Louie says. “We want to get there ahead of time.”

COMPANY

NORTHROP GRUMMAN CORPORATION

Vision: Unmanned spy planes can perform valuable reconnaissance in wartime, reducing the risks to pilots.



Global Hawk drone

DIFFERENT WARS tend to highlight different military technologies. In the recent Afghan conflict, unmanned aerial vehicles have provided sustained, near-real-time intelligence, surveillance and reconnaissance information that has proved to be invaluable to allied commanders. One of the standout performers over the battlefield has been the American RQ-4A Global Hawk, a new aircraft that had not yet entered operational service when the hostilities began. Only through the efforts of Northrop Grumman and U.S. Air Force personnel did the remotely controlled spy

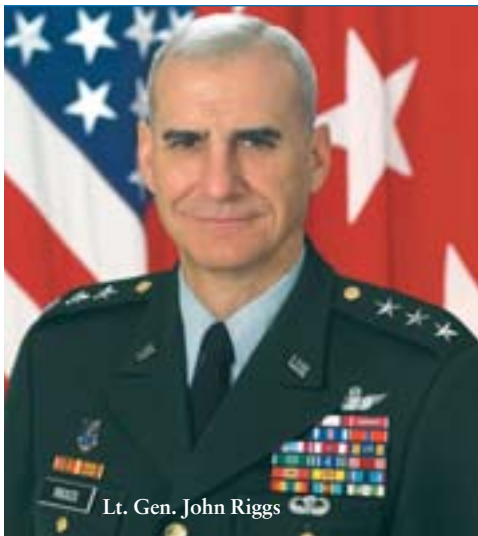
plane make it to the combat zone in time. Despite difficult operational and logistical obstacles, the people and equipment needed to deploy the advanced drones on a wartime footing were put in place in short order. Global Hawk program manager Carl O. Johnson oversaw the team effort by Northrop Grumman Integrated Systems, which is headquartered in El Segundo, Calif. Soon the pilotless aircraft was winging its way high above the mountainous Afghan terrain for as long as 36 hours at a time, delivering high-resolution imagery of the battle zone day and night.

POLICY LEADER

LT. GEN. JOHN RIGGS

Director, U.S. Army Objective Force Task Force

Vision: The 21st-century army needs technologically advanced combat forces to defeat new types of foes.



Lt. Gen. John Riggs

SINCE THE END of the cold war, the U.S. Army has faced major changes to its global war-fighting doctrine. With large-scale hostilities becoming less likely and the prospect of smaller, far-flung “unconventional” conflicts more the norm, the army’s force structure—what it has to fight with—is under fundamental reconsideration. John Riggs has been influential in leading the often contentious, even acrimonious debate among military planners about how to transform today’s ground divisions into high-tech fighting units of the future. One great controversy is the configuration of its heavy battlefield maneuvering forces, which are currently based on the 70-ton Abrams battle tank. The policy deliberations center on whether next-generation combat vehicles should be so massive, given the difficulty of transporting them by air. If Riggs’s untiring arguments are successful, future combat systems could comprise a highly flexible array of manned and robotic land cruisers, directed-energy weapons and unmanned aerial vehicles, all linked by advanced intelligence sensors and data networks.

JULIE JACOBSON AP Photo (top); DEPARTMENT OF DEFENSE AP Photo (middle); U.S. ARMY OBJECTIVE FORCE TASK FORCE (bottom)

BUSINESS LEADER

MANFRED STEFENER

Founder and CEO, Smart Fuel Cell Company

Vision: Fuel cells can be made small enough to power even mobile consumer products, from flashlights to laptops.

EVERYONE WITH A LAPTOP has at some point wished for a better battery, but Manfred Stefener believes that miniature fuel cells would be the cleanest, most efficient answer to those dreams. His optimism showed in his business plan, which won a 1999 competition in Munich, where his company is now headquartered. Starting Smart Fuel Cell in 2000, Stefener built a 20-member team and set about creating a prototype. The resulting fuel cells, he maintains, could be used as external power supplies or integrated into portable devices. They would then be applicable to the huge disposable-battery market, which is \$4 billion annually in the U.S. alone.



Manfred Stefener

The cells consume methanol and water and give off unnoticeable amounts of air, carbon dioxide and water. Many other fuel cells use hydrogen for fuel, but it is more expensive and potentially more combustible than methanol. When a conventional battery runs down, we throw it away, tossing caustic chemicals into landfills. When one of Stefener's fuel cells runs out of methanol, he removes a methanol cartridge and puts in another. It takes just a few seconds, and fuel already in the cell keeps it running until the new cartridge is in place—meaning you can change the cartridge while the fuel cell continues to power whatever device it is running. The replacement cartridges' potentially low cost—\$3 to \$5, according to Stefener—would make them attractive because they would last three to five times as long as conventional batteries with the same power rating.

One of the major hurdles for fuel cells has been shrinking them to a practical size. A conventional fuel-cell stack is rarely smaller than a mini refrigerator. But Stefener's first product, the Remote Power System SFC 25.2500 R, is as small as a shoe box and can provide 25 watts of power for 100 hours on one fuel cartridge. So far it is available to Smart Fuel Cell's industrial partners. In January the company began producing the fuel cells; it expects to manufacture more than 1,000 of them by the end of the year. Because the power packs are still too big for a laptop or a handheld gadget, Stefener is aiming current models at camping gear and remote sensors. His team has also built a prototype called the Mobile Office System, which has the proportions of a mid-size paperback and can run a laptop for eight hours. By 2004 Stefener plans to produce 100,000 fuel cells annually. He also hopes that his products will be ready to compete in the market with lithium-ion batteries in just a few years.

RESEARCH LEADER

KEN DEERING

Co-founder and vice president of engineering, Wind Turbine Company

Vision: Windmills built "backward" can provide the greatest power output.

FOR DECADES, ENGINEERS have tried to construct less expensive turbines that capture wind power efficiently. Most have placed the blades on the upwind side of the tower, primarily out of convention, which requires that in strong winds the blades be rigid enough not to deform and hit the tower. Ken Deering put the blades on the downwind side, as a few other rebels before him had. But he bested his predecessors by developing a hinge that lets the blades flex with the wind, thereby reducing the stress on the entire structure. Consequently, he can build taller towers to lift the blades to the strongest winds. He also can use less material in the structure, cutting construction costs. In March, Deering and his colleagues installed a 500-kilowatt turbine in Los Angeles and connected it to the local utility grid. The Wind Turbine Company, based in Bellevue, Wash., has also secured the rights to build a 30-turbine wind farm in Washington State. If erected, it will be the first real testament to his towering design.



Deering's wind turbine

POLICY LEADER

EDDIE O'CONNOR

Chief executive, Airtricity

Vision: Wind power can lead Ireland toward a future of green energy.

EDDIE O'CONNOR is showing policymakers in Ireland that a shift toward environmentally friendly electricity is justified. In recent years, Ireland's legislators have expressed some desire to reduce air pollution but have moved cautiously. By deregulating the country's electric industry, however, they opened the door for renewable energy, and O'Connor jumped in with wind power. Airtricity in Dublin has already built and operates two wind farms and has begun importing electricity from hydropower plants in Scotland. The power flows down the Moyle Interconnector, a new electric cable that joins Northern Ireland to the Great Britain power



Eddie O'Connor

grid. Airtricity now serves 14,000 business customers and was valued at \$65 million in January. O'Connor is planning a 200-turbine wind farm four miles from Ireland's southeastern coast that would generate 520

megawatts. The facility would be the world's biggest offshore wind farm, providing 10 percent of Ireland's electricity demand. The company has also secured permits for six more onshore wind farms, each rated at 400 megawatts. This would give Ireland about 3,000 megawatts of wind power—substantial, considering that the entire generating capacity of Ireland in 2000 was 4,054 megawatts.

COMPANY

SPECTROLAB and THE NATIONAL RENEWABLE ENERGY LABORATORY

Vision: Highly efficient photovoltaics can be produced at low cost.

IN JUNE the National Energy Resources Organization honored Spectrolab in Sylmar, Calif., and the National Renewable Energy Laboratory (NREL) in Golden, Colo., for constructing the most efficient land-based solar cell. Spectrolab grew the so-called triple-junction cells, which consist of three layers of different crystals: gallium indium phosphide, gallium arsenide, and germanium. Researchers at NREL then added antireflection coatings and metal contacts to make the cells functional. In laboratory tests, the cells converted 34 percent of the energy in sunlight to electricity, beating the previous world record by about 2 percent. Equally important, Spectrolab used standard production equipment to manufacture the cells and built them on a low-cost base of germanium; they are more than 40 percent more efficient than other mass-produced cells. Spectrolab plans to put these cells in large-scale systems, including ones for utility companies. The cells improve the odds of making photovoltaics commercially successful, and NREL officials predict that their design could lead to ever higher efficiencies.



New solar cell

WIND TURBINE COMPANY (top); JASON CLARKE (middle); SPECTROLAB (bottom)



ENVIRONMENT

BUSINESS LEADER

JOAN BAVARIA

CEO, Trillium Asset Management, and founding chair, CERES

Vision: Wall Street should judge companies not merely on their financial returns but on the kind of world they support.



Joan Bavaria

JOAN BAVARIA HAS BEEN AT THE FOREFRONT of the movement to guide investment by social and environmental criteria since its inception more than 20 years ago. She continues to cajole, praise and savage firms according to their behavior. Last year alone, one organization she founded, the Coalition for Environmentally Responsible Economies (CERES), urged shareholders at ExxonMobil's annual meeting to demand the establishment of corporate environmental goals. CERES also threatened to end its cooperation with General Motors because of the company's opposition to stricter fuel-economy standards for SUVs.

In 1981, after several years of working in conventional banking, Bavaria co-founded the Social Investment Forum, an association of lending firms dedicated to investing in corporations chosen on social and environmental merit. She was the forum's president for four years and a member of its board for eight. In 1982 she founded Trillium, then called Franklin Research and Development Corporation, to establish a portfolio of such investments, organizing it as an employee-owned firm that does pro bono work and donates 5 percent of before-tax profits to charity. In 1989 Bavaria founded CERES to promote her standards of corporate behavior.

Potential investors had considered criteria other than the purely financial long before Bavaria came on the scene, but typically they did so for reasons of personal propriety. Muslims, for instance, would invest only in noninterest-bearing instruments, and nonprofit institutions would eschew holdings in firms involved in gambling, alcohol, birth control—whatever they considered unseemly at the time. It was Bavaria and the movement she inspired that first grasped the possibility of influencing corporate behavior by coordinated investing and, no less important, the publicity that accompanies it.

Boston-based Trillium—named for a three-petaled flower, representing the three investment goals of ecology, economy and equity—has 35 employees and manages only \$650 million. Yet the respect that the fund commands in the worldwide community of social investors—which, according to the Social Investment Forum, controls more than \$2 trillion—gives it substantial clout. "Sell" recommendations and other advice issued by Trillium have affected the disposition of such companies as the Body Shop and Ben & Jerry's. Both companies had won support among socially conscious investors and were thus particularly sensitive to Trillium's censure.

The social-investing community that Bavaria helped to mold can make life difficult even for those companies that have no particular following among environmentalists. In 1989, when the breakup of the *Exxon Valdez* drenched Alaska's Prince William Sound in crude oil, Bavaria titled a list of 10 corporate guidelines she was in the process of drafting the "Valdez Principles." The name caught the eye of many CEOs, who, not wanting to be tarred as Exxon had been, acceded to the objectives; today they are known as the CERES Principles. To gain and retain CERES's imprimatur, these companies—which include BankAmerica, Sun Microsystems and Ford Motor Company—must submit periodic reports to CERES regarding their environmental goals.

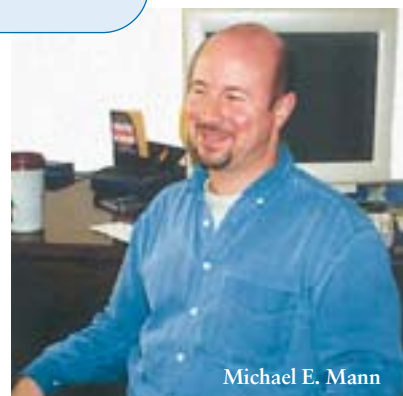
RESEARCH LEADER

MICHAEL E. MANN

Assistant professor of environmental sciences,
University of Virginia

Vision: More scientific evidence will resolve the debate over global warming.

WHILE JUST A POSTDOC at the University of Massachusetts at Amherst in the late 1990s, Michael Mann made a splash with his studies of climate variability over the past 1,000 years. Using tree-ring and ice-core measurements to estimate global temperatures, he and his colleagues Raymond Bradley and Malcolm Hughes devised a graph that was dubbed "the hockey stick" because it showed a sharp upward swing in temperatures after 1850. The research helped to prompt a shift in the position of the United Nations International Panel on Climate Change, which reported last year that humans were responsible for most of the global warming over the past century. Mann was also the lead author of the panel's chapter on climate variability. He has subsequently buttressed his findings with more studies. Mann's work figured prominently in the Environmental Protection Agency's statement earlier this year that humans are gradually heating the planet, and although the Bush administration quickly repudiated that report, the evidence is becoming harder and harder to deny.



Michael E. Mann

COMPANY

PUBLIC SERVICE ELECTRIC AND GAS (PSEG) OF NEW JERSEY

Vision: Power plants can pollute less and still be profitable.

PUBLIC SERVICE ELECTRIC AND GAS has earned a reputation among environmentalists as the white knight of the utility industry. The company supports nationwide emissions standards for power plants, saying that rules would help level the industry's playing field and reduce business uncertainty. PSEG won plaudits for its response earlier this year to the Environmental Protection Agency's concerns about two coal-fired power plants in New Jersey. Instead of fighting the EPA's Clean Air Act



PSEG plant in Hamilton Township, N.J.

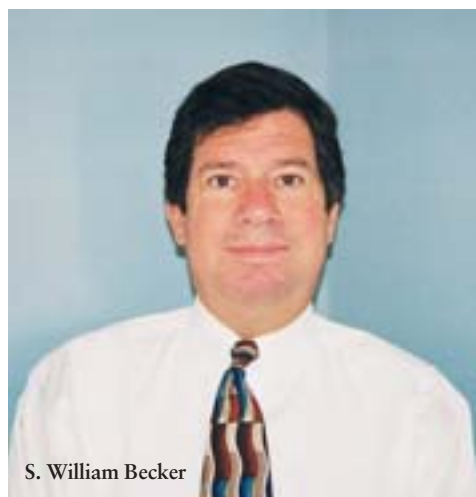
enforcement actions in court, the utility quickly settled by agreeing to spend more than \$300 million on state-of-the-art pollution controls. Scrubbers will remove 90 percent of the sulfur dioxide and 83 percent of the nitrogen oxide that the plants produce. Most significantly, PSEG also agreed to reduce the plant's output of carbon dioxide—the chief greenhouse gas—even though the step isn't required. That act set a fine precedent for the industry.

POLICY LEADER

S. WILLIAM BECKER

Executive director, State and Territorial Air Pollution Program Administrators

Vision: Reducing vehicle emissions will save lives.



S. William Becker

BILL BECKER'S JOB as the lobbyist for the nation's pollution-control agencies made him the prime mover behind one of the most important environmental accomplishments of 2002. In the last year of the Clinton administration, the Environmental Protection Agency announced a rule to cut 95 percent of diesel-truck emissions by 2007. But the cleanup plan was thrown into doubt when President George W. Bush ordered federal agencies to review all Clinton-initiated rules. To keep the plan alive, Becker assembled a coalition that included the Natural Resources Defense Council, the Clean Air Trust, the American Lung Association and even British Petroleum, which acknowledged it could cheaply produce the low-sulfur fuel that would be needed to cut emissions. The full-court press convinced the EPA not to ax the new rule. The plan overcame another hurdle this year when the D.C. Circuit Court of Appeals upheld the EPA's decision. The agency estimates that the rule will prevent 8,300 premature deaths each year.



MANUFACTURING

BUSINESS LEADER

SUNLIN CHOU

Senior vice president and general manager, Technology and Manufacturing Group, Intel Corporation

Vision: The Moore's Law dictate of smaller, faster, cheaper chips should continue indefinitely.

INTEL IS THE STANDARD-BEARER for Moore's Law—named after founder Gordon Moore, who almost four decades ago predicted that the number of transistors on a chip would double about every 18 months. The Intel executive who ensures that the credo prevails in the dozen or so Intel factories is Sunlin Chou, who coordinates the translation of increasingly complex technologies into reliable manufacturing.

In the past year Chou has overseen Intel's introduction of new materials for chip wiring and insulation as well as its lithographic process for patterning the 0.13-micron generation of chips. (At one time the industry believed that practical technology could not be pushed any smaller than the one-micron generation.) The relatively smooth rollout of these advanced materials and processes is a result of a manufacturing system established in the mid-1980s. Chou headed the first team that overhauled chip-making at that time, when Intel faced a strong threat from Japanese semiconductor manufacturers. The key organizational innovation was to give the engineers on development teams responsibility for taking a new chip design all the way from the research stage through the first commercial production of high-quality chips. This approach eliminated the handoff from development to manufacturing teams, which usually entailed months or even years of additional tweaking. This seemingly simple change shortened the product introduction cycle for new chips from three to two years, contributing to Intel's emergence as the world's leading semiconductor company.

Chou also became a champion of Intel's "distributed research" model, in which the company marshals outside resources such as universities, national laboratories and start-up companies to help it identify and develop the best early-stage ideas into commercial products. "Sunlin's the one" who has led the transformation, says G. Dan Hutcheson of VLSI Research, a market research firm that tracks semiconductor technologies.

Intel's biggest current project that adheres to this model focuses on extreme ultraviolet lithography. Chou, an avid scuba diver and underwater photographer, heads a board that oversees research by several national laboratories on this technique, intended to allow the patterning of chips with features as small as 10 nanometers. Working with outside groups—and commissioning highly directed research endeavors—avoids the formation of large, central research facilities, which often have trouble aligning their research mission with that of the corporation's business goals. Extreme ultraviolet lithography may ensure that the Moore's Law Express continues to race along at least throughout the rest of Chou's career, if not forever.



Sunlin Chou

SCIENTIFIC AMERICAN



Scientific American

*is pleased to honor these 50 individuals,
teams, companies and other organizations.*

*Through their many accomplishments
in 2001–2002, they have demonstrated clear,
progressive views of what
our technological future could be,
as well as the leadership, knowledge and expertise
essential to realizing those visions.*

Congratulations.

RESEARCH LEADERS OF THE YEAR



Stephen Goff

Syngenta's Torrey Mesa
Research Institute



Huanming Yang

Beijing Genomics Institute



Jun Yu

University of Washington
Genome Center

*Led the effort to sequence
the genome of rice,
the world's most important
food crop.*

AGRICULTURE

ALLISON A. SNOW Ohio State University
Showed the potential for unintentional transfer of genetically modified traits to weedy plants.

G. STEVEN BURRILL Burrill & Company
Advanced the cause of biotechnology by demonstrating its prudent investment value.

SANDRA L. POSTEL Global Water Policy Project
Advocated sweeping changes aimed at preserving the world's dwindling supplies of freshwater.

PRODIGENE College Station, Tex.
Produced transgenic corn that could be the basis for an edible AIDS vaccine.

CHEMICALS AND MATERIALS

ANTHOULA LAZARIS and COSTAS KARATZAS
Nexia Biotechnologies
Created transgenic goats that can manufacture superstrong spider silk in their milk.

RANDY HOWARD Cargill Dow
Marketed "green" plastics made from corn that are economically competitive with conventional products.

JON S. CORZINE U.S. Senate, New Jersey
Legislated for higher security and safety standards at industrial facilities to defend against terrorism.

MOTOROLA Schaumburg, Ill.
Integrated components made of different semiconductors onto single high-performance chips.

COMMUNICATIONS

MARC GOLDBURG ArrayComm
Invented method for improving wireless services by beaming signals directly to mobile users.

MASOOD GARAH MeshNetworks
Tested systems for forging ad hoc high-speed wireless networks of mobile devices.

LAWRENCE LESSIG Stanford University Law School
Argued against interpretations of copyright that could stifle innovation and discourse online.

XM SATELLITE RADIO Washington, D.C.
Offered nationwide satellite-based radio broadcasts with digital audio quality and no commercials.

COMPUTING

JOHN KUBIATOWICZ University of California, Berkeley
Designed a highly distributed data storage system that could be shared by millions of users simultaneously.

PAUL HORN IBM Research
Directed his company and others to build more robust computer systems needing less care and supervision.

ANN BEESON American Civil Liberties Union
Fought to ensure that personal freedoms would be preserved online and in digital media.

MATRIX SEMICONDUCTOR Santa Clara, Calif.
Developed vertically integrated microchips that could lower prices while boosting performance.

DEFENSE

JOAQUIN H. CASTRO Pratt & Whitney Space Propulsion
Led the team that designed and built a functional prototype of a scramjet engine.

GILMAN LOUIE In-Q-Tel
Used venture capital to help foster needed intelligence-gathering technologies for U.S. security.

LT. GEN. JOHN RIGGS
U.S. Army Objective Force Task Force
Oversaw the high-tech transformation of ground forces for fighting new kinds of wars.

NORTHROP GRUMMAN CORPORATION El Segundo, Calif.
Rapidly deployed its Global Hawk unmanned spy plane for reconnaissance in Afghanistan.

ENERGY

KEN DEERING Wind Turbine Company
Designed new wind turbines that are more efficient and produce more power.

MANFRED STEFENER Smart Fuel Cell Company
Led the commercial development of miniature fuel cells small enough to power mobile devices.

EDDIE O'CONNOR Airtricity
Guided Ireland's plans to build a massive wind-power station at sea.

SPECTROLAB and THE NATIONAL RENEWABLE ENERGY LABORATORY Sylmar, Calif., and Golden, Colo.
Demonstrated photovoltaic cells with record-breaking high efficiencies.

ENVIRONMENT

MICHAEL E. MANN University of Virginia
Conducted influential research into global climate change that affected international policies.

JOAN BAVARIA Trillium Asset Management and Coalition for Environmentally Responsible Economies
Promoted social and environmental goals by guiding investments toward companies with responsible policies.

S. WILLIAM BECKER State and Territorial Air Pollution Program Administrators
Lobbied successfully for pollution controls that will cut automotive emissions.

PUBLIC SERVICE ELECTRIC AND GAS State of New Jersey
Responded constructively to concerns about polluting emissions from utilities.

MANUFACTURING

R. STANLEY WILLIAMS, PHILIP KUEKES and YONG CHEN
Hewlett-Packard Laboratories

JAMES HEATH University of California, Los Angeles
Invented nanotechnology devices that might eventually surpass those etched into chips.

SUNLIN CHOU Intel Corporation
Oversaw the development of technologies for making chips whose smallest features are about the size of a virus.

ALICE H. AMSDEN Massachusetts Institute of Technology
Identified strategies for economic development that could be of singular value to non-Western countries on the rise.

NANOOPTO CORPORATION Princeton, N.J.
Devised methods for integrating the disparate components of optical computing onto a single chip.

MEDICAL DIAGNOSTICS

GARY W. SMALL University of California, Los Angeles
Demonstrated that the medical imaging technology PET can give a clear, early diagnosis of Alzheimer's disease.

PETER D. MELDRUM Myriad Genetics
Led his company's development of diagnostic products based on patients' genetic information.

ERIC GOEMAERE
Doctors Without Borders/Médecins Sans Frontières
Brokered agreements making AIDS therapies more available to the poor in South Africa.

CELERA DIAGNOSTICS Alameda, Calif.
Found genes associated with various illnesses and began to develop new tests for diagnosing them early.

MEDICAL TREATMENTS

ANTHONY J. ATALA
Children's Hospital and Harvard Medical School
Demonstrated that cloning can be used to produce transplantable organs and tissues.

EMILIO A. EMINI Merck & Co.
Mobilized his company to invest substantially in AIDS vaccine research.

KOFI A. ANNAN United Nations
Formed the U.N. Global Fund to Fight AIDS, Tuberculosis and Malaria and lobbied for billions in funding.

IDEC PHARMACEUTICALS San Diego, Calif.
Introduced the first commercial radio-conjugated monoclonal antibody for fighting cancer.

TRANSPORTATION

DEAN KAMEN DEKA Research and Development Corporation
Invented his groundbreaking Segway personal transport to widen individuals' travel options.

HIROYUKI YOSHINO Honda Motor Co.
Directed his company's progressive position on improving fuel efficiency and lowering emissions.

FRAN PAVLEY California State Assembly
Legislated state automotive CO₂-emissions standards that will improve standards nationally.

XCOR AEROSPACE Mojave, Calif.
Built and tested extremely small rocket engines that might someday change the economics of launches.

GENERAL TECHNOLOGY

ALEXANDER PINES and JOHN CLARKE University of California, Berkeley, and Lawrence Berkeley National Laboratory
Demonstrated the theoretical feasibility of low-power MRI scanners for diverse medical uses.

JEFFREY IMMELT General Electric Company
Maintained his company's extensive commitment to funding basic research.

RUSH HOLT U.S. House of Representatives, New Jersey
Spearheaded efforts to resurrect the congressional advisory Office of Technology Assessment.

CAMBRIDGE DISPLAY TECHNOLOGY Cambridge, England
Developed and promoted the use of light-emitting polymers in commercial product displays.

*BUSINESS LEADER
OF THE YEAR*



Geoffrey Ballard
General Hydrogen Corporation

*Advocated and oversaw the development
of fuel cells as automotive energy sources.*

MARK GILBERT

RESEARCH LEADER

NANOTECHNOLOGY ENTHUSIASTS DREAM of a time when circuits with molecule-size components might complement or replace semiconductor electronics. Crucial to that hope is the development of techniques suitable for manufacturing circuitry on that mind-bogglingly small scale. These investigators have received a series of patents that establish them as leaders in molecular computing. At a September conference in Sweden, Stanley Williams announced that Hewlett-Packard Laboratories had made a 64-bit memory device using molecular switches that fit inside a square micron and has a bit density 10 times as great as that of today's silicon memory chips. The labs built the circuits using nanoimprint lithography, a molding method pioneered by Stephen Y. Chou, founder of NanoOpto [see profile below]. Yong Chen received a patent in August for the lithography technique. And in a November 2001 patent, Williams, Philip Kuekes and James Heath detailed how to ensure that electrical signals in a complex grid of molecular logic circuits do not interfere with one another.

R. STANLEY WILLIAMS, PHILIP J. KUEKES, YONG CHEN and JAMES HEATH

Williams, director of quantum science research, Kuekes, member of the technical staff, Chen, researcher, Hewlett-Packard Laboratories; and Heath, professor of chemistry and biochemistry, University of California, Los Angeles

Vision: Self-assembling circuits for molecular computing could eventually supplant semiconductor microchips.



R. Stanley Williams



Philip J. Kuekes



Yong Chen



James Heath

COMPANY

INTEGRATED CIRCUITS combine transistors, resistors and other electronic components on one monolithic chip. Now the start-up NanoOpto has begun to commercialize an innovative manufacturing technology that does the same for the filters, waveguides and laser components used in optical networking. The technique could bring great efficiencies to the manufacture of optical components, which until recently required hand assembly. The brainchild of Princeton University professor Stephen Y. Chou, NanoOpto's process relies on novel quartz or silicon molds

NANOOPTO CORPORATION

Vision: Building ever smaller optical components will improve the performance of the most powerful networks.

to fashion features as small as 10 nanometers. This approach contrasts with conventional semiconductor manufacturing, which uses optical beams to carve out the analogous structures. Optical lithography, however, has difficulty patterning structures smaller than the wavelength of its light source. NanoOpto's tiny parts can potentially improve the performance of optical networks by bending light in ways that cannot be achieved with classical optical devices. In June, Chou also demonstrated the manufacture of nanoelectronic circuitry using a similar mold process.

ALICE H. AMSDEN

Professor of political economy, Massachusetts Institute of Technology

Vision: One-size-fits-all economic policies are ill suited for poor countries looking to become industrialized.

POLICY LEADER

ALICE AMSDEN'S INCISIVE ANALYSES of how nations from China to Mexico have developed a healthy industrial base in recent decades are making economists think hard about their policies. In her book *The Rise of "The Rest": Challenges to the West from Late-Industrializing Economies* (Oxford University Press, 2001), she extracts lessons for other societies that are now treading a similar path. One distinguishing characteristic of "the rest"—economies that successfully undertook industrial development—was a robust

manufacturing experience that relied on technologies already commercialized elsewhere. Government development policies were a critical factor in building a manufacturing base. James M. Cypher of California State University at Fresno recently wrote of Amsden's work: "If you have time to read only one book on development economics in the next year, read this book.... From her meticulous work arise extremely convincing axioms and principles regarding the dynamics of economic development."



Alice H. Amsden

CARLOS GONZALEZ San Francisco Chronicle (top: Williams, Kuekes and Heath); HEWLETT-PACKARD LABORATORIES (top: Chen); COURTESY OF ALICE H. AMSDEN (bottom)



MEDICAL DIAGNOSTICS

RESEARCH LEADER

GARY W. SMALL

Director, Aging and Memory Research Center, University of California, Los Angeles

Vision: Medical scanners can provide a definitive, early diagnosis of Alzheimer's disease.

GARY SMALL DEVELOPED a technique that unveils the beginnings of Alzheimer's disease in people. Scientists around the world have sought such an early-warning marker ever since German physician Alois Alzheimer noticed clumps and snarls in the neurons of a woman who died of mental illness in 1906. These irregularities in the brain—now called amyloid plaques and tangles—serve as the primary sign of Alzheimer's, which ruins brain structures that serve memory and other mental abilities. Small's work focuses on assessing and treating the disease, which now afflicts 10 percent of people older than 65.

In the November 7, 2001, issue of the *Journal of the American Medical Association*, Small and his research team describe a study of 284 patients with symptoms of dementia. About half the group received a positron emission tomography brain scan (better known

as a PET scan), clinical assessment and follow-up exams for at least two years. The other half received a PET scan and a onetime clinical assessment. Patients who later died were autopsied. Before the scan, patients were given an intravenous injection of fluorodeoxyglucose, which is taken up by the brain and reveals differences in glucose metabolism in regions of the brain that can be seen in a PET scan. In the first group, Small and his colleagues compared the initial PET scans with the subsequent course of the dementia and found that the scans predicted the outcome—getting or not getting Alzheimer's—with between 75 and 91 percent accuracy. In the second group, autopsies showed Alzheimer's in 70 percent of the patients, and their PET scans accurately predicted the disease's presence or absence in 88 percent of the cases.

Beyond simply looking at differences in brain metabolism, though, Small wanted to image the amyloid plaques and tangles. In the February issue of the *American Journal of Geriatric Psychiatry*, Small and his team describe injecting a protein called FDDNP, which included a radioactive marker, into 16 patients between the ages of 62 and 85. Half of them suffered from dementia. The FDDNP accumulated in brain regions rich in amyloid plaques and tangles, and Small and his colleagues concluded that greater accumulation of the protein correlated with lower scores on memory tests.

Until now, physicians have been limited to cognitive tests, whose results could be ambiguous. Only a brain autopsy could provide a certain diagnosis of Alzheimer's. Although no research confirms that plaques or tangles actually cause Alzheimer's, a person is more likely to experience more severe symptoms of Alzheimer's as the concentration of plaques and tangles increases. Small's noninvasive technique thus provides a potential tool for diagnosis and eventually perhaps some guidance for treatment. Small maintains that this method could lead to determining the levels of amyloid plaques and tangles long before dementia occurs.



Gary W. Small

U.C.L.A.

BUSINESS LEADER



Peter D. Meldrum

IN A DECADE OF RUNNING Myriad Genetics in Salt Lake City, Peter Meldrum's compassion for people and fascination with science turned his company into a leader in developing therapeutic and diagnostic products based on genes and proteins. Investigators at Myriad find the sequence of nucleotides in the human genome that make up disease-related genes and then decipher the jobs of the proteins made by those genes. With such information, Meldrum and his colleagues are devising a series of tests that reveal a patient's genetic predisposition for various cancers, including breast and ovarian. In the past year they launched two new tests for colon and skin cancers. To make their tests available commercially, Meldrum's team created two subsidiaries, Myriad Pharmaceuticals and Myriad Genetic Laboratories. The operations are collaborating with pharmaceutical leaders, including Abbott Laboratories, Bayer, and Eli Lilly and Company, to broaden the firms' lines of therapeutics.

PETER D. MELDRUM

Director, president and CEO, Myriad Genetics

Vision: Understanding a patient's genetic makeup could be the key to better cancer prevention and therapy.

POLICY LEADER

ERIC GOEMAERE

Head of Mission, Doctors Without Borders/
Médicins Sans Frontières

Vision: Effective antiretroviral treatments should be available and affordable in AIDS-plagued underdeveloped countries.

THE PERSISTENT ERIC GOEMAERE fights for better AIDS treatment in South Africa. Although more than 10 percent of the country's population is infected with HIV, the government had dragged its feet on providing modern antiretroviral treatments because some officials considered the therapies too expensive and complicated. That changed recently when Goemaere reached an agreement with the government of the Western Cape and began

a program in Khayelitsha for distributing antiretrovirals to infected pregnant women. These drugs can reduce HIV symptoms and limit transmission of the virus from mother to child. To answer the government's objections, Goemaere imported less costly generic drugs and initiated programs to help patients take them as directed. The result: 92 percent of the mostly terminal-stage patients in the program ended up with undetectable levels of HIV. Now South Africa's government wants to make antiretroviral therapy available for mothers-to-be to protect unborn children.



Eric Goemaere

CELERA DIAGNOSTICS

Vision: Assessing specific groups of genetic markers will unveil the early stages of many diseases.

COMPANY

CELERA DIAGNOSTICS in Alameda, Calif., uses genetics to devise tests that reveal diseases at early stages. The company specializes in sequencing the genomes of individuals (producing genotypes) and doing it fast—it expects that it will soon generate many genotypes every day. Thus equipped, scientists can look at constellations—groups of genetic markers—that are turned on or off in healthy and diseased populations. New tests can check a patient's blood or tissue sample for the activity of genes in a constellation linked to a specific disease. Abbott Laboratories recently joined forces with Celera to take advantage of the smaller firm's genotyping and tests. Celera is already running large-scale searches for markers that would indicate early stages of chlamydia and hepatitis C, and it is developing an HIV test that will help medical scientists assess drug resistance in the virus.

MYRIAD GENETICS, INC. (top); CHRISTIAN SCHWETZ (bottom)



MEDICAL TREATMENTS

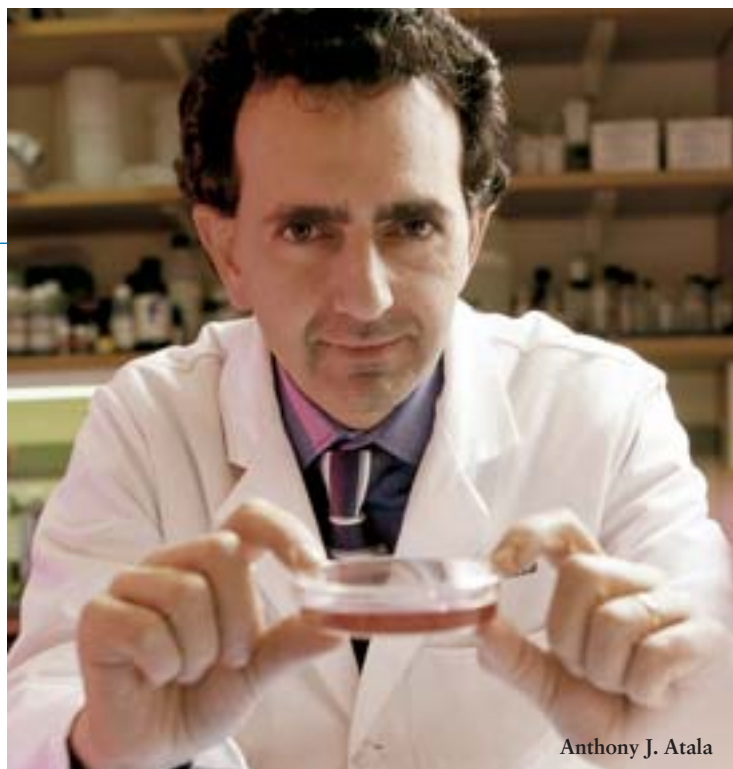
RESEARCH LEADER

ANTHONY J. ATALA

Director of tissue engineering, Children's Hospital, Boston, and associate professor of surgery, Harvard Medical School

Vision: Cloned organs and tissues could treat a wide range of diseases.

FOR MORE THAN FIVE YEARS, Anthony Atala has pursued the goal of engineering spare body parts. Atala has demonstrated that tissue engineering can be used to generate organs and tissues that carry out normal functions once transplanted into a host animal—without being rejected by the animal's body. He has successfully constructed canine bladders by isolating bladder cells from dogs and growing them on sphere-shaped polymer forms. Once the regrown bladders are transplanted back into the donor dogs, they are able to function as usual. Atala is currently awaiting permission from the Food and Drug Administration to try the same procedure with human patients whose own organs must be removed because of diseases such as cancer.



Anthony J. Atala

Atala also has used cloning to create transplantable tissues in cows. First he teamed with scientists at Advanced Cell Technology (ACT) in Worcester, Mass.—the company that announced in November 2001 that it had generated the first cloned human embryo. Next Atala and researchers from ACT, the Mayo Clinic and the University of Miami School of Medicine made transplantable heart and skeletal muscle and kidney tissue. The group removed the genetic material from cow eggs and injected skin cells taken from the ears of other cows into the empty eggs. Technicians allowed the injected eggs to divide several times and then placed the early embryos into the wombs of cows that had been treated with hormones. After the embryos grew there for several weeks, the researchers isolated tissue from them and transplanted it underneath the skin of other cattle. The heart muscle “patches” were capable of beating spontaneously, and the kidney tissue could generate urine. The cows receiving the transplants showed no signs of rejecting the tissues.

Although human cloning remains controversial—Congress is still debating whether to ban or regulate the technology—Atala's work shows the promise of therapeutic cloning. Human applications would not require the embryos to be placed in a womb, because scientists have identified stem cells in very early embryos that can give rise to all tissues of the body. They culture the cells in various conditions, and the cells randomly and spontaneously form cardiac muscle, liver or kidney tissue, and so on; researchers are now trying to determine ways to order up a particular tissue. (Embryonic stem cells have not yet been isolated from cattle.) Human cloned tissue could be placed directly into a patient.

Replacement organs made using cloning and tissue engineering could be an important resource. At any given time in the U.S., roughly 80,000 people are on lists awaiting a transplant of an organ from a cadaver. Many die before a suitable organ becomes available or are forced to accept an organ that isn't a perfect match for their tissue type, which often leads to serious rejection problems. Even patients who receive a matched organ have no guarantees: they must take antirejection drugs for the rest of their lives.

BUSINESS LEADER

EMILIO A. EMINI

Senior vice president for vaccine research, Merck & Co.

Vision: Pharmaceutical companies can devise a vaccine that prevents people already infected with human immunodeficiency virus (HIV) from developing AIDS.

MANY RESEARCHERS have despaired of ever finding a vaccine against AIDS. Although people are living longer with HIV since the advent of antiretroviral drugs, no medication has yet been shown unequivocally to clear the infection. Accordingly, there has been no model of natural immunity for scientists to follow in designing a vaccine. Yet Emilio Emini has mobilized Merck, headquartered in Rahway, N.J., to spend millions on AIDS vaccine research, making it a standout among large pharmaceutical companies, which are often reluctant to develop vaccines. At a key AIDS conference this past February, Emini and his colleagues presented data that have revived hope for an AIDS vaccine. The results came from human trials of two vaccine formulations: one composed only of DNA encoding an HIV protein, the other made of the same snippet of DNA stitched inside an innocuous cold virus "vector." Both generated strong cellular immune responses in volunteers. Emini and his colleagues anticipate that the vaccine might help people infected with HIV to live even longer.



Emilio A. Emini

POLICY LEADER

JUST THREE DISEASES collectively killed 5.7 million people worldwide in 2001. For that reason, in June 2001 Kofi Annan formed the United Nations Global Fund to Fight AIDS, Tuberculosis and Malaria and called for members of the U.N. to raise \$7 billion each year to bring the diseases under control around the globe. He succeeded in garnering \$2.1 billion in monetary commitments for the fund in its first year, even though the U.S.

KOFI A. ANNAN

Secretary-general, United Nations

Vision: With strong support from industrial nations, a truly international effort could stamp out the major killer infections.



Kofi A. Annan

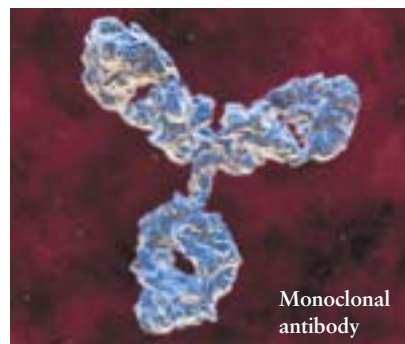
pledged only \$500 million. Annan continues to push the wealthy countries of the north and west to acknowledge the dangers these three diseases pose to global public health and to pay for interventions by fully funding the initiative. Not only does his activism encompass prevention efforts—such as donations of condoms and treated bed nets—but he has made clear that he expects the fund to help cover treatment costs for those who already have the diseases.

COMPANY

IDEC PHARMACEUTICALS

Vision: Monoclonal antibodies coupled to lethal molecules can selectively kill cancer cells.

MONOCLONAL ANTIBODIES are proteins of the immune system that bind to specific invaders and target them for destruction by immune cells. In the 1980s they were touted as "magic bullets" that would make it possible to cure cancer, but they fell flat in initial human tests. In 1998 Genentech made the first blockbuster monoclonal antibody-based drug, Herceptin, for women with metastatic breast cancer. Herceptin is thought to work by blocking receptors for growth factors on tumor cells. But for years, scientists have wanted to couple monoclonals with radioisotopes or toxins so they could directly kill the cancerous cells they target. Such conjugated monoclonal drugs have proved difficult to develop and to shepherd through the regulatory process. This past February, however, IDEC in San Diego won federal approval to market Zevalin, the first radioconjugated monoclonal antibody, for the treatment of a type of non-Hodgkin's lymphoma.



Monoclonal antibody

MERCK & CO. (top); NAJLAH FEANNY Corbis SABA (middle); JEFF JOHNSON (bottom)



TRANSPORTATION

RESEARCH LEADER

DEAN KAMEN

Founder, DEKA Research and Development Corporation

Vision: Novel types of transportation can free cities of traffic and greatly expand the mobility of disabled people.



Dean Kamen

FEW INVENTIONS IN RECENT YEARS have so captured the limelight as Dean Kamen's Segway, a battery-powered, adult-size two-wheeled transporter that rights itself if it starts to tip over in any direction. This past year Segway LLC, the company Kamen set up to commercialize his invention, began lending demonstration models to potential customers in business and government. Two aspects of the vehicle command attention: its control scheme and its power source. The controls employ five gyroscopes and 10 computers to stabilize the scooter, eliminating the need for brakes and steering wheels—the driver merely leans one way or the other to move or to stop. The power source is now based on standard batteries, but Kamen intends to replace them eventually with his souped-up variant of the Stirling engine, a fuel-efficient, external-combustion device often likened to a steam engine.

One bump in the road is the device's safety—some have argued that the vehicle's light weight offers little protection to the driver on the road, and its relatively high speed makes it dangerous to pedestrians on the sidewalk. Nevertheless, 18 states have approved the Segway for use on sidewalks.

Segway owes its fame not only to its charm and its promise of thinning urban traffic but also to the teasing way in which it was originally touted and then unveiled. Technology pundits who had been let in on the secret sang its praises, but then Kamen had to keep mum to secure patent rights and other commercial details. The media had a field day speculating about what was then code-named "IT," apparently for "individual transport."

Control themes have run through Kamen's inventive work ever since his childhood, when he rigged a system of pulleys to make his bed. In high school he came up with a way to automate audiovisual displays that found application in planetariums and public halls and gave him the cash he needed to continue his tinkering. With more than 150 patents to his credit, he has continued to automate and miniaturize technologies for personal use, particularly in medicine, where his insulin pump and his portable dialysis machine have allowed outpatients to enjoy levels of physiological control that hospitals once might have had difficulty achieving. Kamen founded his first biomedical company, AutoSyringe, in 1976.

Even the Segway has a biomedical cousin, the IBOT, which is actually a far more ambitious apparatus—as reflected in its estimated price of \$25,000, eight times as much as the expected cost for the Segway. The IBOT's four wheels are yoked in two pairs that can each rotate around an axis. When aligned left to right, the pairs allow normal, motorized movement; when the alignment rotates, inchwormlike, the pairs flip over one another to climb stairs. And when aligned up and down, they stand on tiptoe so the seated rider can look a cocktail-party interlocutor in the eye.

BUSINESS LEADER

HIROYUKI YOSHINO

CEO, Honda Motor Co.

Vision: Automakers should manufacture cars that burn less fuel more cleanly and that people will actually want to drive.

AN ENGINEER'S ENGINEER, Hiroyuki Yoshino symbolizes Honda's go-it-alone attitude to problems both technical and commercial. Last year, after he assumed stewardship of Hon-



Hiroyuki Yoshino

da, the company's U.S. division broke ranks with the major American car companies by declining to participate in an advertising campaign against a Senate bill to raise fuel-efficiency standards. It also refused to oppose a California bill to reduce greenhouse gas emissions. Yoshino's advocacy of applying the strict emissions standards for cars to sport utility vehicles has won praise from environmental groups. His stance is an extension of his engineering days, when he designed an engine so clean it did not require a catalytic converter to meet then current emissions standards. Honda generally works alone on fuel cells and hybrid vehicles, rather than forming development partnerships, as its rivals tend to do. With sales up, Yoshino's company has proved that it isn't all that hard, really, to be green.

POLICY LEADER

LAST YEAR FRAN PAVLEY'S BILL to establish standards for automotive carbon dioxide emissions became law in California. The victory, by a single vote, capped two years' effort by the freshman legislator and former schoolteacher, who all along refused to weaken the bill in any way. "She took up the fight with great vigor despite strong opposition from industry—it was an act of courage," says Roland J. Hwang of the Natural Resources Defense Council. California, the fifth-largest economy in the world and home to 25 million cars, has long leaned on automakers to cut emissions. In the past, however, the state cared only about emissions that contributed to the formation of smog in California itself. Now, for the first time, Pavley's law will impose standards meant to improve the climate of the entire world.

FRAN PAVLEY

California State Assembly, 41st District

Vision: The fight against global warming should be waged on a regional as well as a national and international level.



Fran Pavley

COMPANY

XCOR AEROSPACE

Vision: Low-cost rocket engines could revitalize the aerospace industry.

XCOR IS A SMALL, SCRAPPY COMPANY built on a desert airfield in Mojave, Calif. A handful of the firm's engineers developed a liquid-oxygen/alcohol rocket the size of a soda can that can deliver 400 pounds of thrust. The team attached two of these rockets to a homebuilt single-passenger plane and got world-famous pilot Dick Rutan to put this bird—dubbed the E-Z Rocket—through a series of test flights. CNN was there to cover the flights (which began in July 2001 and are continuing), but the effort was more than just a publicity stunt. Starting and restarting this type of craft in midflight had never before been tried. Although XCOR has thus far limited the E-Z Rocket to low altitudes, a scaled-up version—which would cost about \$10 million, the same as a Lear jet—could conceivably travel to the uppermost reaches of the atmosphere and make space tourism a reality.



E-Z Rocket

ITSUO INOUE AP Photo (top); COURTESY OF FRAN PAVLEY (middle); RON SIDDE/ANTELOPE VALLEY PRESS AP Photo (bottom)



GENERAL TECHNOLOGY

COMPANY

CAMBRIDGE DISPLAY TECHNOLOGY

Vision: Plastic displays might one day replace cathode-ray tubes and liquid-crystal displays.

THE WORLD glows with countless electronic displays, from watch faces to gigantic video billboards, almost all of which are based on cathode-ray or liquid-crystal technologies. But in the past year Cambridge Display Technology (CDT) in England has significantly improved the resolution and contrast of its prototype light-emitting polymer (LEP) displays. It has simultaneously become the engine behind the nascent LEP industry's aggressive drive to commercialization.

In the late 1980s University of Cambridge scientists Richard Friend and Andrew Holmes discovered that light-emitting diodes could be made of polymers. In 1992 they founded CDT to develop commercial applications. After almost a decade, the first consumer products containing LEP displays are now reaching the market; their niche is in small alphanumeric screens that show simple sets of segmented characters. Philips is selling an electric shaver that has a Cambridge LEP readout, and Delta Optoelectronics is marketing an MP3 player with the same innovation. In 2003 CDT expects its LEP displays to appear in cellular phones and handheld electronics. Instrument panels are another potential near-term market. Meanwhile Mark IV Industries in Amherst, N.Y., is working with CDT to develop much larger screens for road and transportation signage.

CDT's ultimate goal is for LEP displays to displace the cathode-ray tubes and liquid-crystal displays (LCDs) of televisions and computer monitors. The market research firm DisplaySearch predicts that the organic light-emitting diode market, of which LEPs are a major sector, will be \$4 billion by 2007. CDT is fanning the flames by energetically licensing its technology and forming joint ventures with major electronics manufacturers, including Philips, Delta Electronics, DuPont Displays and Osram. The approach brings together CDT's expertise in organic light-emitting diodes and its partners' experience in making commercial electronic products.

Now that they are maturing, LEP displays have a variety of potential advantages over established technologies. Most notably, they can be made thin and flexible enough to roll up like a plastic sheet and can be manufactured in almost any shape. Unlike LCDs, LEPs do not need an ambient light source—typically provided by a backlight and filters—so they can be thinner and lighter and consume less power. LEPs also offer wider viewing angles than LCDs do, approaching 180 degrees. LEP displays are fast (having submicrosecond response times) and operate at low voltages (unlike field-emission displays); each pixel can be designed to emit any color in the visible spectrum simply by modifying its underlying polymer. Manufacturing them is potentially easier than making LCDs or plasma displays.

With Seiko Epson in Japan, CDT has developed and is now commercializing an ink-jet printing technique for manufacturing LEP displays. The partnership has already used this approach to craft high-resolution, full-color displays. It remains to be seen whether LEP displays the size of computer monitors can be mass-produced with the high performance and low cost of existing displays, but CDT plans to try.



LEP display

RESEARCH LEADER

ALEXANDER PINES and JOHN CLARKE

Pines, chemistry professor, University of California, Berkeley, and Lawrence Berkeley National Laboratory; Clarke, physics professor, U.C. Berkeley, and head of materials physics, LBNL

Vision: Medical magnetic resonance imaging machines can become far smaller, less expensive and therefore more versatile.



Alexander Pines



John Clarke

NUCLEAR MAGNETIC RESONANCE (NMR) and magnetic resonance imaging (MRI) machines rely on intense magnetic fields—fields so strong they can reel in metal objects from across the room. The powerful field—around one tesla, or 30,000 times the earth's magnetic field—teases apart shifts in the NMR response of atoms in the molecules of a person's body. In March researchers at U.C. Berkeley published results of NMR experiments

that used fields as low as a few microteslas. Chemical shifts are indistinguishable in such ultraweak fields, but a second effect, called J coupling between atoms, is detectable. Rhodesian-born NMR pioneer Alexander Pines and English superconductor expert John Clarke led the collaboration. Although significant obstacles remain, the new technique could lead to inexpensive low-field MRI machines for doctors or even handheld body analyzers like those seen in *Star Trek*.

BUSINESS LEADER

JEFFREY IMMELT

Chairman and CEO, General Electric Company

Vision: Investing in innovation will propel a company through times of economic uncertainty.



Jeffrey Immelt

JEFFREY IMMELT TOOK over as CEO of General Electric on September 10, 2001. The next day saw the deaths of two employees to terrorism, a colossal

loss for GE's insurance business and a drop in orders for the company's aircraft engines. In the coming months GE's stock slumped to roughly half its value. Yet in January 2002 Immelt announced plans to modernize and expand GE's research center in Niskayuna, N.Y., and to

devote resources to five- to 10-year studies in nanotechnology, photonics, advanced propulsion and biotechnology—a big change from GE's classic focus on one- to two-year projects geared toward new products. Measured against spending by research behemoths such as IBM and Lucent Technologies, the new investment is not huge, but it signals a commitment to innovation in the face of business adversity.

RUSH HOLT

U.S. Representative of New Jersey

Vision: The federal government needs better, unbiased scientific briefings and advice to guide intelligent decision making.

POLICY LEADER

REPRESENTATIVE RUSH HOLT IS ONE of two Ph.D. physicists in Congress (the other is Vern Ehlers of Michigan). Formerly a plasma physicist at Princeton University and now in his second congressional term, Holt is spearheading an effort to reestablish the Office of Technology Assessment, an agency that supplied Congress with expert analyses of scientific and technological issues from 1972 to 1995. His bill, H.R. 2148, would reinstate the office immediately. Opinions differ about how a new OTA would best be structured, but debates such as those on stem cells and cloning show how important it is to provide the top levels of government with better insight and perspective on such fundamental matters. Holt is also an ardent advocate of increasing federal nondefense spending on basic science and is a guardian of funding for education initiatives such as teacher training in math and science.



Rush Holt

CONTRIBUTORS TO THE SCIENTIFIC AMERICAN 50 include Mark Alpert, Steven Ashley, Graham P. Collins, Carol Ezzell, Mark Fischetti, W. Wayt Gibbs, Mike May, Philip E. Ross and Gary Stix.



Broadcast versions of this section will air beginning November 26 on *National Geographic Today*, a program on the National Geographic Channel. Please check your local listings.