November 12, 2006

Scientific American 50

By The Editors

A group of scientists have detailed how to create materials that can redirect light around an object and make it invisible. This possible precursor to the ultimate camouflage demonstrates the depth of ingenuity of the 2006 SCIENTIFIC AMERICAN 50 awards.

These accomplishments go beyond invoking the Invisible Man. Drawn from the worlds of research, business and policymaking, a good number of the names on our list have in common an interest in leading technological innovation as a force for the public good: A fundamental understanding of the molecular processes that produce the mind-erasing devastation of Alzheimer's. A hybrid car that recharges by simply plugging into the wall. A billionaire who gives up much of his fortune to improve the state of global health.

Some of the inventions of this year's winners may soon be found at big retailers or in hospital dispensaries. Yet many of the researchers garnering accolades concentrated on basic questions, occupying themselves, for instance, with learning about the mechanisms that transform one stem cell type into a more specialized cell type--knowledge that will help answer the critical question of whether these wondrous biological entities will ever prove useful in clinical practice. Throughout the list of winners, that same theme reasserts itself: the most fundamental science precedes the technology that is eventually put to service in treating Alzheimer's or fashioning new devices that might outperform silicon electronics.

November 12, 2006

Scientific American 50: Research Leader of the Year

By JR Minkel

RESEARCH LEADER OF THE YEAR
Angela Belcher
Massachusetts Institute of Technology
This eclectic investigator draws inspiration from nature's genius for building things at the nanoscale

The crux of nanotechnology is the problem of self-assembly, getting uncooperative atoms to link and align themselves up in precise ways. We know it can be done, of course: life persists by turning molecules into complex biological machinery. How fitting, then, that one of today's most creative materials scientists, Angela Belcher of the Massachusetts Institute of Technology, has turned to nature for assistance. Belcher has pioneered the use of custom-evolved viruses in synthesizing nano-scale wires and arrays, fusing different research disciplines into something uniquely her own.

Belcher got her start with abalone, a cousin to oysters. The mollusk had evolved a system for accreting a hard shell from calcium carbonate, the same material of which chalk is made. As a graduate student at the University of California, Santa Barbara, Belcher elucidated the molecular assembly scheme abalone employed to grow its shell and tweaked a key protein to accelerate the growth process. Soon head of her own lab, she was standing on her desk one day, pondering the periodic table of elements and wondering how far she could push nature's ability to manipulate inorganic elements.

Abalone had learned to control calcium. She decided that she would teach nature to work with the rest of the list. "The aim is to work our way through the whole periodic table and be able to design materials of all kinds in a controlled way. My biggest goal is to have a DNA sequence that can code for the synthesis of any useful material," she told MIT's *Technology Review*.

She started with the DNA sequence of the M13 bacteriophage, a long, tubular virus six nanometers wide. She engineered a version of the virus that latched onto quantum dots, nanometer-size specks of semiconductor with desirable electromagnetic properties, by repeatedly selecting the virus particles best able to cling to the dots. In a matter of months she evolved a virus that held a chunk of material steadfastly on one end, like a ball and chain. By dissolving the virus particles she could make them align themselves thickly like hairs all capped with quantum dots. The viruses are packed so densely that they essentially form thin films, which can be stacked closer together than other means can quickly achieve.

More recently she customized M13 to stud its length with metal particles such as cobalt oxide and gold, yielding metal nanowires that could be used in high energy-density electrodes. By growing the virus on a film she could make a thin, flexible metal oxide coating suitable for storing energy chemically. Those could be incorporated, for example, into thin-film batteries that coat the surface of a device or fit into nonstandard shapes. Belcher co-founded Cambrios Technologies in Mountain View, Calif., to turn some of her demonstrations into commercial devices such as solar cells and light-emitting diodes. She has her sights on other organisms too and has started working with yeast in order to engineer more complex nanostructures.

To meet her goals, Belcher has committed herself to adding a new field to her repertoire every five years. Starting as a biochemist, she has incorporated materials chemistry, electrical engineering and molecular biology, in effect starting from scratch each time. Like the abalone's shell, this bit-by-bit accretion yields solid results.

Related Links

Angela Belcher's home page

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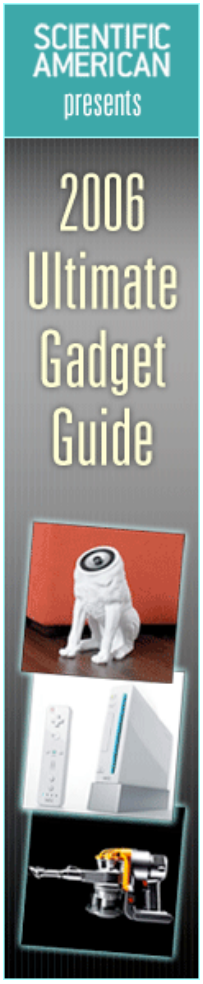
Scientific American 50: Business Leader of the Year

By JR Minkel



BUSINESS LEADER OF THE YEAR
Swiss Re
Zurich, Switzerland
A top insurer highlights the dire consequences that could result from global warming

When one thinks of those trying to spread the word about the risks of global warming to society, one of the most reputedly staid industries probably doesn't leap to mind. Global reinsurer Swiss Re is looking to change that image. Having long had its eye on climate change, the company co-sponsored a major report, released late last year, highlighting the potentially disastrous economic consequences of global warming.

The insurance industry makes money by successfully predicting the rates of fire, flood and other natural disasters. As a reinsurer, Swiss Re assumes the risk from primary insurers that issue policies to individuals and businesses. Climate change poses a special problem for the industry because it has the potential to dramatically change the rates of extreme weather events, perhaps to a point where insurers would not be unable to keep up. "Imagining the cascade of effects of climate change calls for a new approach to assessing risk," according to the Climate Change Futures report, issued last November. The report notes: "Insurers and reinsurers find themselves on the front lines of this challenge since the very viability of their industry rests on the proper appreciation of risk."

The report, co-sponsored by the United Nations Development Program and published jointly with the Center for Health and the Global Environment at Harvard Medical School, outlines recent trends in climate and extreme weather and traces the possible effects of two different climate change scenarios on prospects for heat waves and flooding, infectious and chronic disease, and managed and natural resources. Both scenarios are based on unchecked greenhouse gas emissions. In the first, escalating rates of extreme weather are accompanied by outbreaks of infectious disease and pests, straining many sectors of the economy and challenging the abilities of developed nations to cope.

In the second scenario, dramatic climate change leads to repeated heat waves, chronic water shortages and ecosystems pushed past their breaking points. Sudden, wide-scale disruptions to the global economy crash financial markets, as weather events create unpredictable, unmanageable risk. The report details some of the possible disruptions to the energy sector alone: blackouts during heat waves, oil distribution and power transmission undermined by repeated storms and melting tundra, and reduced capacity for hydroelectricity and cooling of power plants.

Swiss Re has a history of sensitivity to climate change concerns. The company's London building is a massive gherkin-shaped building designed to use half the energy of a typical building its size. In 2003 Swiss Re announced it was establishing a 10-year plan to become greenhouse "neutral," meaning it would reduce or offset the net carbon emissions of its employees to zero.

Last year the company joined the Chicago Climate Exchange, a voluntary market for greenhouse gas emissions trading. With the release of its 2005 report, Swiss Re called on governments and global industry to take much stronger action to mitigate the consequences of climate change: "[L]ittle action has been taken by most governments or businesses to address the potential costs of climate change. As all insurers know, however, risk does not compliantly bow to the political or business agenda."

Related Links

Swiss Re

November 12, 2006

Scientific American 50: Policy Leader of the Year

By JR Minkel and Gary Stix

POLICY LEADER OF THE YEAR
Al Gore
U.S. Vice President
The former presidential candidate is the preeminent spokesperson on climate change

It sounds improbable: a documentary film about global warming, starring Vice President Al Gore, has become the third-highest-grossing documentary of all time. After his loss in the 2000 presidential election, Gore began giving a talk on global warming to audiencesaround the world. *An Inconvenient Truth* is the film version (also appearing in book form) of his multimedia presentation. Remarkably, its heavy use of PowerPoint slides actually adds to the narrative, which interweaves explanations of climate science with defining episodes from Gore's life to convey a mix of alarm and hope.

The film is a paragon of clear science communication. It explains the workings of complex physical phenomena, such as the jet stream, while chronicling the reality of glaciers receding and the increase in carbon dioxide emissions and global temperatures. Gore, meanwhile, succeeds in bringing the "moral imperative" of reducing greenhouse gases to a personal level, attempting toconvince viewers that their own actions can make a difference.

His appeal to individual responsibility is enhanced by the way the former politician, often lampooned for his stiff speaking style, gives the viewer a glimpse of his own life. In one of the film's strongest scenes, Gore recounts how his older sister's death from lung cancer led his family to stop growing tobacco-a painful metaphor for the industrial world's predicament in coming to grips with excess atmospheric carbon.

The film provoked commentary from across the political spectrum. After its release, the conservative Competitive Enterprise Institute attacked: "Carbon dioxide-they call it pollution; we call it life." But movie critics drew attention to it by generally lavishing praise: "You owe it to yourself to see this film," urged Roger Ebert. "If you do not, and you have grandchildren, you should explain to them why you decided not to." The achievement of *An Inconvenient Truth* has been to bring the most important scientific and technical issue of our time into the public view better than anything before in print or film.

Related Links

An Inconvenient Truth

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Scientific American 50: SA 50 Winners and Contributors

RESEARCH LEADER OF THE YEAR: **1. Angela Belcher, Massachusetts Institute of Technology**

BUSINESS LEADER OF THE YEAR: **2. Swiss Re**

POLICY LEADER OF THE YEAR: **3. Vice President Al Gore**

Other Research, Business and Policy Leaders

More Than Government Grants
4. Michael Kremer, Harvard University (policy)
5. Scott Johnson, Myelin Repair Foundation (policy)
6. Kathy Giusti, Multiple Myeloma Research Foundation (policy)
7. Christiane Nüsslein-Volhard, Christiane Nüsslein-Volhard Foundation (policy)
8. Warren E. Buffett, investor/philanthropist (policy)

On the Road to Green
9. Iogen Corporation (business)
10. Michikazu Hara, Tokyo Institute of Technology (research)
11. DaimlerChrysler (business)
12. General Motors, DaimlerChrysler and BMW (business)
13. EDrive Systems and Hymotion (business)

Unlocking Alzheimer's
14. John R. Cirrito and David M. Holtzman, Washington University in St. Louis School of Medicine (research)
15. Randall J. Bateman and David M. Holtzman, Washington University in St. Louis School of Medicine (research)
16. Robert P. Hammer, Louisiana State University (research)

Beginning to See the Light
17. Igor I. Smolyaninov, University of Maryland (research)
18. John B. Pendry, Imperial College London, David Schurig and David Smith, Duke University, and Ulf Leonhardt, University of St. Andrews (research)
19. Nader Engheta, University of Pennsylvania (research)

The Promise of the Mother Cell
20. Kevin Eggan, Harvard Stem Cell Institute (research)
21. Richard K. Burt, Northwestern University, Feinberg School of Medicine (research)
22. Laurie A. Boyer and Richard A. Young, Whitehead Institute for Biomedical Research (research)
23. Susan L. Lindquist, Whitehead Institute for Biomedical Research (research)
24. Representative Diana DeGette of Colorado and Representative Mike Castle of Delaware (policy)

Smart Tags Get Smarter
25. IMEC (business)
26. Eugenio Cantatore, Philips Research Laboratories (business)
27. Hewlett-Packard Laboratories (business)

Chicken-Wire Electronics
28. Andre K. Geim, University of Manchester, and Philip Kim, Columbia University (research)
29. Walter de Heer, Georgia Institute of Technology (research)
30. Prabhakar R. Bandaru, University of California, San Diego (research)
31. Ray H. Baughman, Mei Zhang and Shaoli Fang, NanoTech Institute, University of Texas at Dallas (research)

Growing Replacement Parts
32. William R. Wagner and Michael S. Sacks, University of Pittsburgh (research)
33. Cytograft (business)
34. Shulamit Levenberg, Technion-Israel Institute of Technology

Robots on the Move
35. Stanford Racing Team (research)
36. Jessy W. Grizzle, University of Michigan at Ann Arbor (research)

DNA Sequencing on the Cheap
37. George M. Church, Harvard Medical School (research)
38. 454 Life Sciences (business)
39. H. Kumar Wickramasinghe, IBM Almaden Research Center (business)

Material Progress
40. Natalia Dubrovinskaia, University of Bayreuth (research)
41. Pulickel M. Ajayan, Rensselaer Polytechnic Institute (research)
42. Antoni P. Tomsia, Lawrence Berkeley National Laboratory (research)
43. Daniel E. Morse, University of California, Santa Barbara (research)

Sight Savers
44. Larry I. Benowitz, Children's Hospital Boston (research)
45. Elizabeth Goldring, Center for Advanced Visual Studies, Massachusetts Institute of Technology (research)
46. Protagoras Cutchis, Johns Hopkins University (research)

Of Brain Maps and Saving the Internet
47. Christopher Monroe, University of Michigan at Ann Arbor, and David J. Wineland, National Institute of Standards and Technology (research)
48. Timothy Wu, Columbia University (policy)
49. Andrew J. Turberfield, University of Oxford (research)
50. Paul G. Allen, Allen Institute for Brain Science (research)

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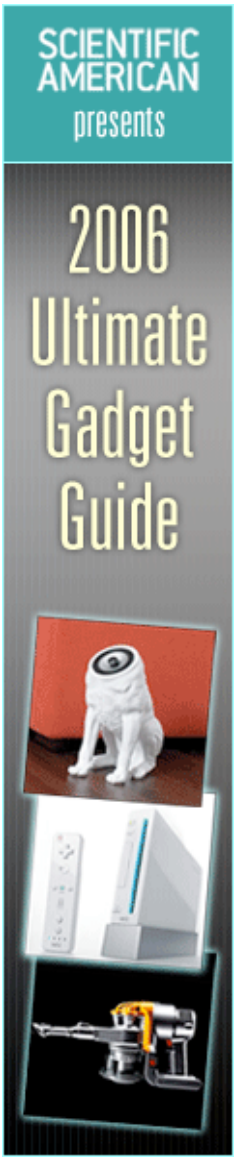
November 12, 2006

Scientific American 50: Trends in Research, Business and Policy

More than Government Grants



Entrepreneurial ingenuity focuses on finding money and ideas to advance medical science

To lift the burden of infectious diseases in poor nations, Harvard University economist **Michael Kremer** has advocated a kind of artificial market for vaccines. In Kremer's scheme, a donor country or institution would commit to paying a certain sum for the development of a vaccine and would purchase it at a high price per dose. After that, the company would supply the vaccine to poor countries at a low price. The Group of Seven nations has asked for a pilot proposal from the World Bank that would test Kremer's suggestion for vaccinations against a trial disease.

Kremer's approach is one of many that have marshaled unprecedented creativity to chart new paths for medical research. A different attempt is the brainchild of **Scott Johnson**, a 50-year-old former businessman who is waging a personal battle against multiple sclerosis. His Myelin Repair Foundation, established in 2003, has persuaded five of the field's top university researchers to merge their laboratories and create a more businesslike plan for developing treatments, with patents from any discoveries controlled by the foundation. "Before we started this, if you asked how long it would be until we found myelin drug targets, it would have been 15 years," Johnson says. "With this process it may be five years."

Similarly, four leading cancer centers have linked efforts to coordinate clinical trials, share resources and pool their findings on a deadly bone disease: multiple myeloma, a blood cancer that erodes bones and kills quickly. Leading the project is **Kathy Giusti**, a pharmaceutical executive who learned that she had multiple myeloma in 1996. A graduate of Harvard Business School, Giusti set up the Multiple Myeloma Research Foundation, which has raised $60 million for research.

Christiane Nüsslein-Volhard, a pioneering geneticist and co-winner of the 1995 Nobel Prize in Physiology or Medicine, has taken perhaps the most personal approach. With her own money and a $100,000 award from Unesco-L'Oreal's Women in Science Program, she has launched a foundation in her own name that offers grants to young female scientists to pay for baby-sitters and household help. "We try to find the gifted ones," she says, "where it would be a real pity if they dropped out. We say: use these funds to buy yourself time away from household matters."

Warren E. Buffett's innovation may be the most surprising of all. In what *Fortune* magazine described as "typical Buffet: rational, original, breaking the mold of how extremely rich people donate money," the world's second richest man is giving away 85 percent of his wealth, most of it to the Bill and Melinda Gates Foundation. In an open letter to the couple, Buffett wrote of his admiration for what the foundation is accomplishing and his desire to "materially expand its future capabilities. . . . Both of you have applied truly unusual intelligence, energy and heart to improving the lives of millions of fellow humans who have not been as lucky as the three of us." The example of Buffet and Bill and Melinda Gates is inspiring other top executives and

research professionals to bring their imaginations to bear on conducting the business of research.-- *Michelle Press*

On the Road to Green

Chemists and automakers mark progress toward environmentally benign fuels and vehicles

Motorists have heard a lot lately about ethanol-based fuels, which burn cleaner than gasoline and derive from renewable, domestic biomass. **Iogen Corporation**, a Canadian biotech firm, has blazed a novel path to production of ethanol-based fuels. Rather than converting relatively high-priced farm crops, researchers there decided to focus on making ethanol by transforming the tough, sugar-bearing cellulose in low-cost agricultural residues and waste. Iogen has pioneered fuels from cellulosic ethanol by developing enzymes that can extract the sugars from wheat and barley straw. The company is running the world's first and only demonstration "biorefinery" that can convert as much as 40 tons per day of straw into cellulosic ethanol.

Another renewable, alternative fuel is biodiesel--predominantly vegetable oils that are processed to serve as a clean-burning diesel fuel. Current methods for turning the unwanted fatty acids in these oils into esters so the resulting liquid can be burned in diesel engines consists of treatment with strong acids (such as sulfuric acid) or bases (such as sodium hydroxide), among others. These processes are expensive, energy inefficient, chemically wasteful and environmentally destructive. **Michikazu Hara** of the Tokyo Institute of Technology in Yokohama and several research colleagues in Japan have demonstrated that a charred mixture of inexpensive sugars, starch or cellulose can be treated with sulfuric acid to create a solid acid catalyst for making biodiesel that is completely insoluble, cheap to prepare and easy to recycle. In addition, it exhibits substantially greater catalytic activity than liquid sulfuric acid.

Just as researchers are working to make biodiesel fuels that are more widely used, automotive engineers are toiling to make diesel engines operate more cleanly. Although experts consider modern diesel-powered cars to be relatively green, the higher temperatures at which they burn fuel leads to undesirable nitrogen oxide (NOx) and soot emissions. A leader in the quest to make greener diesel engines is the German-based automaker

DaimlerChrysler, which recently introduced BLUETEC technology--a modular exhaust treatment system that cuts nitrogen oxide and soot output significantly. BLUETEC technology helps create the cleanest diesel power train yet, making it possible for diesel cars to meet the most stringent U.S. emission standards.

Another automotive engine technology that gets better mileage than standard internal-combustion power plants and hence, produces less carbon dioxide for each mile driven, is the gasoline-electric hybrid, which marries a gasoline engine with electric motors. Current hybrid vehicles save fuel in stop-and-go, urban driving, but provide little mileage benefit when on the highway. The new two-mode hybrid system from a consortium that includes **General Motors, DaimlerChrysler and BMW** boosts fuel efficiency at both low and high speeds. As in most hybrids, the two-mode system recaptures braking energy as battery power, shuts down the engine at stops and can operate at slow vehicle speeds on electricity alone. But unlike current single-mode hybrid systems, the two-mode vehicle offers enhanced fuel efficiency not only in city traffic but also on the highway, improving combined mileage by 25 percent.

Yet an additional way to raise the environmental performance of hybrid vehicles is to give them the means to store power from the electrical grid so that at times they can run on electricity alone instead of drawing power from a generator driven by a gasoline-burning, internal combustion engine. These plug-in hybrids came closer to commercial reality when two companies, **EDrive Systems**, a joint venture of EnergyCS and Clean-Tech in Calif., and **Hymotion**, a Canadian company, each introduced plug-in hybrid upgrade kits for the Toyota Prius. EDrive's ystem, a larger replacement for the hybrid car's lithium-ion battery system will cost from $10,000 to $12,000. The Hymotion add-ons are supplementary lithium-ion battery systems for fleets. Orders orders greater than 100 vehicles will cost $9,500 each. The new battery packs do not change the basic operation of the Prius; all-electric power is limited to low speeds. Either unit can be recharged by connecting it to a standard household electrical outlet. In the wake of these developments, the road to a greener, more sustainable energy future seems to be opening up--*Steven Ashley*

Unlocking Alzheimer's

Understanding the workings of a key protein may presage treatments

With the elderly segment of populations ballooning worldwide, the race to defeat that grim corollary of aging, Alzheimer's disease, is becoming all the more urgent. And this year saw several encouraging advances on that front. In what reviewers described as a "technological tour de force," **John R. Cirrito and David M. Holtzman** at Washington University School of Medicine traced production of the destructive Alzheimer protein, known as amyloid-beta, to the junctions between neurons called synapses and directly linked synaptic activity to amyloid-beta increases.

Nerve cells communicate across the synaptic gap by releasing pulses of chemicals, and Cirrito's team found that these neurotransmitter spurts were accompanied by releases of amyloid-beta from the same area. The experiments not only established a likely neuronal storage locale and discharge mechanism for amyloid-beta, which goes on to wreak havoc in the intercellular spaces of the brain, they identified a probable cause for the protein's release in the synaptic activation itself. Although the discovery does not necessarily mean that heavy brain activity is to blame for Alzheimer's damage, it may explain why some of the most chronically active brain regions are also most severely affected in Alzheimer's patients.

One key to counteracting those effects is detecting the disease early, and another feat by

Holtzman with **Randall J. Bateman**, also at the W.U. School of Medicine, should make that possible. They have devised a test that measures manufacture and disposal of amyloid-beta in the brain. The pair created a marked version of the amino acid leucine, which neurons normally use as a building block for the amyloid-beta protein, and then administered it to healthy young human subjects.

Bateman later looked for the appearance of a resulting marked amyloid-beta in the volunteers' spinal fluid and found that the protein was cleared slightly faster than it was made. The test could also be used on Alzheimer's sufferers, however, to help researchers resolve the longstanding question of whether the disease is caused by abnormally high amyloid-beta production or dysfunctional clearance of the protein. Eventually, the spinal-tap method could look for elevated amyloid-beta in people with early symptoms of suspected Alzheimer's or measure the effects of drug therapies on already-diagnosed patients.

One of those treatments might one day be based on a synthetic protein fragment **Robert P. Hammer** of Louisiana State University has developed to disrupt formation of the plaques believed to provoke massive brain cell death in Alzheimer's patients. The plaques are aggregations of fibers that form when individual amyloid-beta peptides begin abnormally sticking together. Hammer also tweaked building blocks of amyloid-beta, synthesizing a non-sticky version of the amino acids that permit amyloid-beta proteins to bind to each other. Adding the engineered fragments to a test tube of normal amyloid-beta blocked the proteins' ability to form fibers, even after four months' exposure. If it does the same in human brains, tens of millions of Alzheimer's sufferers might finally be liberated from a deadly burden of poisonous plaque.--*Christine Soares*

Beginning to See the Light

Two-dimensional light waves point toward optical imaging of viruses and the Invisible Man

Several years ago, electrical engineer **Igor I. Smolyaninov** deduced the properties of electromagnetic waves on a metal surface by applying the physics of time machines. The University of Maryland professor was studying what has become one of the sexiest areas of materials science: plasmonics, in which light is turned from a three-dimensional wave (a photon) into a two-dimensional one (a plasmon) rippling along, for example, the side of a metal sheet. If you put a droplet of liquid on the sheet, the plasmons can be trapped-just like photons inside a black hole. If you drill a hole through the sheet, the plasmons can travel from one side to the other-just like photons passing through a wormhole, a hypothetical passage between two different regions of spacetime. In fact, the hole might be used to create an analogue to a time machine and cause all the contradictions familiar to aficionados of science-fiction. Smolyaninov reasoned that if time machines do not work, then neither should their analogues, from which he drew conclusions about the behavior of the waves.

Smolyaninov and his colleagues have now used his liquid-droplet black-hole analogue to create a microscope that can see details smaller than the wavelength of the illuminating light-a feat that any physics textbook will tell you is impossible. The key is that plasmons have a shorter wavelength than the photons from which they were converted, so they respond to finer features. In one test, Smolyaninov's team used laser light with a wavelength of about 500 nanometers to generate plasmons with a wavelength of 70 nanometers. A drop of glycerin focused them to form a 2-D image, which a regular optical microscope viewed. The team took pictures of viruses 100 nanometers wide. The system is much easier to use than an electron microscope.

Like plasmonics, the related science of metamaterials-the creation of artificial atoms with optical properties unlike those of any natural atom-is a door into a world so fantastic that it must surely be imaginary, and yet isn't. This spring, metamaterials pioneer **John B. Pendry** of Imperial College, London, along with **David Schurig** and **David Smith** of Duke University, and, independently, **Ulf Leonhardt** of the University of St. Andrews in Scotland showed that a shell of metamaterials can redirect light around an object and render it invisible-not just very dark (as in current stealth technology) but truly invisible. Although such a cloaking device has obvious military applications, the researchers intended it more as an example of what metamaterials can do.

The most immediate practical application for plasmonics is in electronics. Engineers have long sought to harness light for computational purposes, but photons are much harder to work with than electrons are. New materials make it easier. **Nader Engheta** of the University of Pennsylvania and his colleagues have proposed a standardized set of plasmonic components akin to resistors, capacitors and inductors, which could let engineers build circuits using light rather than electricity. Much as sandwiching an electrical insulator between two conductors creates an electrical capacitor, putting a nonplasmonic material (such as a nanometer-size glass bead) in a light beam creates an optical capacitor. A plasmonic material (a metal) acts as an inductor. These devices allow engineers to wire up optical "circuits" like electronic ones. The "current" that flows around the circuit is not the motion of electric charges, but fluctuations in the electric field associated with the light. One day soon, the fantastic world of plasmonics may be hanging from the rack at Radio Shack.--*George Musser*

The Promise of the Mother Cell

Stem cell biology continues to hint at medical benefits to come

A recent research trend has targeted the goal of having one's stem cells and preserving embryos too, a nod to powerful critics such as President George W. Bush. Even if an embryo remains intact-the objective of these studies--it is unclear whether these methods will ever satisfy Bush and others who rail against what they perceive as immoral tinkering with the stuff of life.

Kevin Eggan and his colleagues from the Harvard Stem Cell Institute brought together embryonic stem cells with skin cells, or fibroblasts, creating fusion cells that reprogrammed themselves to resemble embryonic stem cells genetically matched to the donor of the skin cell. These cells would have the versatility to turn into any other cell type-and would not require a cloning procedure that necessitates the destruction of an embryo.

In the near term, fusion cells offer the potential benefit of understanding basic stem-cell biology, allowing for an understanding of how adult cells can be made to revert to a state in which they are capable of transforming into many different cell types. The technique is still inefficient and the reprogrammed cells contain pieces of chromosomes from the original embryonic stem cells, and thus would not offer a patient an exact genetic match, a flaw that researchers are trying to address.

In theory, an understanding of how cells go back to a previous state in their development might one day lead to a drug that could trigger a process whereby a pancreas cell exposed to the compound might return to being a stem cell and then transform into a cell that produces insulin. Because of the long road ahead, researchers emphasized that work on stem cells obtained from embryos should continue.

The promise of stem cells was again reaffirmed by an experimental therapy to treat patients with lupus-a disease in which the patient's immune system targets the body's own tissue. A group led by **Richard K. Burt** of the Northwestern University, Feinberg School of Medicine, removed stem cells from the patient's bone marrow. Drugs then wiped out the population of white blood cells before the stem cells were returned to the body, where they formed new white blood cells that were less likely to make damaging antibodies. In a study of 48 patients, half did not have the disease after a period of five years.

Determining how an embryonic stem cell differentiates into mature cells might eventually allow development of methods to reprogram an adult cell. Those techniques might let the mature cell return to its "pluripotent" state, in which it is capable of turning into different cell types. **Laurie A. Boyer** and **Richard A. Young** of the Whitehead Institute of Biomedical Research and colleagues demonstrated how three proteins control this process.

Another research finding underlined the importance of exploring the complexities of stem-cell biology without satisfying the demand for immediate medical benefits. **Susan L. Lindquist** of the Whitehead Institute and collaborators demonstrated that the prion protein, which causes mad cow disease when malformed, has a critical stem cell-related function in the body in its normal state.

The protein appears to help maintain the body's supply of stem cells that produce blood cells. The Whitehead experimenters demonstrated the role of prions by irradiating mice to kill off blood-producing stem cells. A bone-marrow transplant was then performed to regenerate the blood precursors. In mice that lacked the protein, stem cells gradually lost their ability to reconstitute themselves.

Bush's decision to limit stem cell research to 78 existing cell lines has hindered the field. Today, far fewer cell lines are viable than the original number permitted many of which are contaminated. **Rep. Diana DeGette**, a Democrat, and **Mike Castle**, a Republican tried to loosen restrictions. They succeeded in getting support from their colleagues in Congress but were ultimately stymied by Bush's veto--the first of his administration. No one knows whether stem cell therapies will produce radically new treatments. Without the commitment to continue basic research unfettered by politics, however, that ignorance is sure to continue.--*Gary Stix*

Smart Tags Get Smarter

The next generation of electronic tags promises to outperform RFIDs

The proliferation of radio-frequency identification (RFID) devices over the past decade has been nothing short of remarkable. Millions of motorists rely on the RFID microchips in their E-ZPass cards to speed through tollbooths. Retailers such as Wal-Mart use RFID technology to keep track of their enormous inventories, and some pet owners have even implanted the tiny chips under the skin of their dogs and cats.

But one of the most sweeping promises of the RFID revolution -- that the devices will replace the ubiquitous bar code -- has not yet come to pass because of their cost. Although the simplest RFID tags now cost about 20 cents apiece, the unit price must fall to about one cent to make it economical for manufacturers to attach the devices to every item sold in supermarkets. Such a reduction may not be possible for conventional silicon-based tags, so researchers have been striving to build RFIDs from a cheaper material: plastic.

In 2005 a group of engineers at **IMEC**, a microelectronics company based in Leuven, Belgium, overcame a major technological hurdle by constructing a diode made of pentacene,

an organic compound that has semiconductor properties. Because a diode restricts the flow of electricity to one direction, an oscillating radio-frequency signal transmitted by an RFID reader can induce a direct current in the tag's circuits, enabling the chip to send a return signal. (This signal tells the reader the serial number of the tagged item.) Prior to IMEC's breakthrough, organic devices were considered too slow to power RFID chips, but the Belgian group showed that their diodes could efficiently generate electricity from the high-frequency radio waves used to identify the tags.

The next step came early this year when a group led by **Eugenio Cantatore** of Philips Research Laboratories in Eindhoven, Netherlands, announced that it had built a fully functional RFID tag made entirely of plastic electronics. Such a chip would be much simpler to manufacture than a silicon-based tag because the design could be directly printed onto a plastic substrate. The elimination of complex assembly may pave the way for low-cost RFID tags incorporated into product packaging, providing each item with a unique identification signal instead of a bar code. And because RFID readers have a range of a few meters, supermarket clerks could speed the checkout process by scanning all the contents of a grocery cart at once.

Meanwhile, engineers at **Hewlett-Packard Laboratories** have devised a miniature wireless chip that could eventually replace RFID tags in many applications. Called the Memory Spot, the chip can hold up to four megabits of flash memory and transfer that data to a reader at 10 megabits per second. Whereas an RFID tag carries only about 500 bits -- just enough to store a serial number -- a Memory Spot could contain a short video clip, several images or dozens of pages of text. Measuring a few millimeters across, the chips could be embedded into passports, postcards, pharmaceutical labels and hospital wristbands. The devices, however, are not expected to be commercially available until two to five years from now.--*Mark Alpert*

Chicken-Wire Electronics

Carbon structures provide new devices and remarkable physics

Since the 1985 discovery of buckyballs (such as buckminsterfullerene-a nanoscopic sphere of 60 carbon atoms connected in a pattern similar to a traditional soccer ball), researchers have focused intense attention on various chicken-wirelike carbon structures. They have sought both to uncover the basic chemistry and physics of these novel compounds and to develop micro- and nanoelectronic devices that might someday outperform conventional silicon technology. The latest addition to the menagerie is structurally the simplest: graphene, a flat single layer of carbon atoms bonded together in the standard hexagonal pattern of graphite.

In November 2005, two independent research groups, one led by **Andre K. Geim** of the University of Manchester and one by **Philip Kim** of Columbia University, experimentally confirmed some extraordinary electronic properties of graphene that were first predicted as long ago as 1947. In an ordinary metal or semiconductor, electrons in many ways behave like particles obeying Newton's laws of motion, just with a so-called effective mass that is different from the electron's real mass because of the interactions with the material's lattice of atoms.

In graphene, however, the electrons' effective mass is zero and they behave like elementary particles obeying a version of Einsteinian relativity, albeit in a realm where the ultimate speed limit is about 800 kilometers per second instead of the usual 300,000 kilometers per second. The electrons travel at that limiting speed no matter what energy they have, just as a photon (a particle of light) always travels at the speed of light in a vacuum. The results open up a

remarkable new domain of relativistic physics that can be explored in tabletop experiments.

The development of graphene devices, which might eventually outperform silicon, took a major step forward when **Walter de Heer** of the Georgia Institute of Technology, along with collaborators there and at the National Center for Scientific Research in France, used standard lithography and etching techniques of the microelectronics industry to make graphene circuitry. The group constructed proof-of-principle transistors and looplike structures called quantum interference devices and studied the properties of graphene ribbons. The ease with which graphene can be shaped to order could give it the edge over carbon nanotubes, which are like strips of graphene rolled into long, thin cylinders and which share many of its electronic properties but are much harder to build into the complex, precise patterns required for many devices.

Nanotube researchers are also constantly breaking new ground. **Prabhakar R. Bandaru** of the University of California, San Diego, and his coworkers there and at Clemson University demonstrated a radically new kind of nanotube-based transistor. In previous designs, a broad metal electrode acts as the "gate" that controls the current passing through a nanotube lying on top of it. Bandaru and coworkers instead made use of Y-shaped nanotubes; any one of the three branches can be used as the gate electrode whose voltage controls the current flowing through the other two branches. The absence of the metal gate allows the transistor to be much smaller than its unbranched cousins, providing a possible pathway to miniaturization beyond that possible with conventional silicon microelectronics.

In the field of macroscopic materials made of carbon nanotubes, the group of **Ray H. Baughman, Mei Zhang** and **Shaoli Fang** of the NanoTech Institute at the University of Texas at Dallas, along with their collaborators there and at the Commonwealth Scientific and Industrial Research Organization in Belmont, Australia, developed an efficient new way to make thin sheets of nanotubes that might be rapidly adaptable to commercial production. The procedure sounds disarmingly simple: the researchers attached an adhesive strip to the edge of a "forest" of nanotubes (imagine a dense forest of bamboo reduced to the nanoscopic scale) and then pulled the strip away at a steady speed, drawing out the vertical tubes in the forest to lie in horizontal rows.

They made sheets that were about 20 microns thick, five centimeters wide and one meter long in less than a minute, and nothing stands in the way of scaling up the process to wider and longer sizes. A simple wetting and evaporation process densified the sheets to about 50 nanometers thick. The sheets are strong, lightweight, transparent, highly flexible and electrically conductive, ideally suiting them to be used as electrodes in solar cells, organic light-emitting diodes, displays and artificial muscles. They could also be used as sources of polarized light and in numerous other diverse applications. Whether it is flat as in graphene or rolled up into nanotubes, the chicken-wire form of carbon continues to go from strength to strength.--*Graham P. Collins*

Growing Replacement Parts

Bioengineers now cultivate bladders and blood vessels from scratch

Although we may not be able to re-grow limbs as salamanders do, the human body does have intrinsic regenerative power, and the discipline of tissue engineering has discovered ways to exploit it. Biodegradable scaffolds made of both natural and synthetic fibers can be seeded with cells that come together to form sheets that mimic the body's natural matrix of soft tissue.

With the goal of reproducing the mechanical properties of soft tissue, bioengineers **William R. Wagner and Michael S. Sacks** of University of Pittsburgh have fashioned an inexpensive polymer, polyester urethane urea, into a scaffold. This cylindrical scaffold's strength resembles that of a pulmonary valve because it responds to stress differently depending on the direction in which the stress is applied. During fabrication, living cells can be integrated into the scaffold, and its mechanical properties can be controlled to create a made-to-order patch of tissue.

At an April conference, Wagner claimed that a patch of this biomaterial infused with smooth muscle cells promotes healing and reduced formation of scar tissue in the hearts of rats recovering from cardiac arrest. Vascular tissue (tissue rich with blood vessels) is the hardest tissue to engineer. The researchers hope to repeat the experiment using a patch infused with muscle-derived stem cells in the hopes of even better results.

Already having reached the phase of clinical trials, the California bioengineering company, **Cytograft**, has patented a method for growing blood vessels from a human patient's own cells. The mechanical strength of the vessel comes from fibroblasts (connective tissue cells) arranged in sheets.

These sheets are formed into cylinders and lined with endothelial cells, those taken from the interior of a vein. The vessels take weeks to mature. But their implantation does not spark worries of an autoimmune or inflammatory response as would materials foreign to the patient's body.

In a feasibility trial in Argentina, Cytograft implanted its engineered vessels into two dialysis patients. Neither encountered problems with the implants for at least nine months. The engineered tissue could serve as a replacement for the synthetic shunts currently implanted between a vein and an artery to facilitate the filtering of blood by a machine. At least 30 percent of these shunts fail after just one year. The company's technology might also be used in coronary bypass surgery, and the product may be adaptable for use in children.

One barrier to progress in tissue engineering results from the inability of thick tissue such as muscle, once implanted in a patient, to receive sufficient penetration of new blood vessels from the body's own network to keep the tissue alive. To address that problem, a multi-institution team spearheaded by **Shulamit Levenberg** of Technion-Israel Institute of Technology in Haifa has created small pieces of muscle capable of generating its own blood vessels.

The researchers combined on a plastic biodegradable scaffold three types of cells: myoblasts that become muscle fibers, endothelial cells that form into vessel tubes, and fibroblasts that are the precursors to the smooth muscle cells that stabilize the cell walls. The endothelial cells became vessels, recruited fibroblasts and caused them to differentiate into smooth muscle cells. Once implanted in a rat, less than half the vessels became perfused with blood. But twice as many cells survived when implanted with three cell types than implants made up of myoblasts and fibroblasts unaccompanied by the vessel-producing endothelial cells. The technique might eventually help address the persistent challenge of supplying engineered cells with oxygen and nutrients and allowing them to remove wastes.--*Brie Finegold*

Robots on the move

Improved mathematical models and sensors endow robots with enhanced mobility

In October 2005, teams watched their robots attempt to navigate the rugged Mojave Desert as part of a challenge sponsored by the Defense Advanced Research Projects Agency (DARPA). The previous year's challenge had ground to a halt when none of the competitors completed more than 5 percent of the 150-mile race. But last year, everything changed. Four robots finished the race in fewer than 10 hours, and the winning robot of the **Stanford Racing Team's** robot, fondly named Stanley, clocked speeds as high as 38 mph. This dramatic turn of fortune can be attributed to advances in software and sensors.

While on-board laser and radar systems scanned the terrain, machine learning algorithms tracked and studied the images, Allowing Stanley, a modified Volkswagen Touareg, to quickly swerve around obstacles and negotiate turns. Probabilistic methods for analyzing the road ahead kept Stanley from a common pitfall: hallucinating imaginary obstacles.

While Stanley may have a human name, the two-legged RABBIT has a disarmingly human gait. **Jessy W. Grizzle**, a control theorist at the University of Michigan at Ann Arbor, has tested his new mathematical model of walking and running on RABBIT, whose lower legs taper to wheels rather than feet. Because this robot is not able to statically balance on one leg, the model incorporates the effects of gravity more fully than other models. As scientists endeavor to automate more human tasks, robots may exhibit pleasing form as well as function. --*Brie Finegold*

Sequencing on the Cheap

Optical technology advances toward the $1,000 genome

The exorbitant cost of deciphering a person's genome dropped sharply in 2005, from $20 million to roughly a tenth of that amount. DNA sequencing technology using off-the-shelf equipment devised by **George M. Church** at Harvard Medical School and collaborators at Harvard and Washington University in St. Louis may help realize the federal goal of reducing that price to $1,000 by 2015, which experts say would make it practical to decode an individual's genes for routine medical purposes.

The build-it-yourself method the Church group developed is based on combining widely available and relatively inexpensive microscopes with high-speed digital cameras. Fluorescent tags are attached to each nucleotide of the DNA the researchers wish to read, with one color for each of the four kinds of DNA nucleotide. The cameras feed this color data to computers to be deciphered into DNA sequences. The report they published on their research in 2005 included detailed instructions on how labs could build their own such devices.

A related technique from **454 Life Sciences** in Branford, Conn., also employs cameras coupled with microscopes to sequence DNA, except this method uses light-emitting chemical reactions instead of fluorescent tags. Sequencing also normally relies on bacteria to multiply copies of the DNA target; both new methods instead use a combination of beads to grab the DNA and enzymes to reproduce it. The Church group's version works roughly 20 times faster than conventional sequencing at a cost of $140,000. 454's method has a roughly 100 times higher throughput than conventional sequencing at a cost of about $500,000 a machine.

In contrast to these optical technologies, current gene sequencing relies on electrophoresis, which uses electric fields to separate molecules based on their size and charge. **H. Kumar Wickramasinghe** at IBM Almaden Research Center and his colleagues reported in May on a technique that can sort DNA fragments roughly 100,000 times faster than conventional

electrophoresis, albeit only with snippets up to 40 nucleotides long.

The approach combines electrophoresis with atomic force microscopy, which scans a surface by running extraordinarily sharp probes across it much as a blind person uses his or her fingers to read bumps on a page of Braille. When an electrical field is applied to the probe's tip, molecules will slide up or down its surface at speeds distinct to different kinds of molecules. The researchers note their work could not only help accelerate DNA sequencing, but also deliver molecules onto surfaces with unprecedented control. That level of precision could prove useful in creating circuits in the emerging field of molecular electronics.--*Charles Q. Choi*

Material Progress

Designers have crafted new structures ranging from nanorods to mother-of-pearl

Extraordinary properties emerge as scientists manipulate construction blocks at the nanometer scale. Diamond nanorods discovered by **Natalia Dubrovinskaia** at the University of Bayreuth in Germany and her colleagues pack together into a dense form of is harder than diamond. In August 2005, the scientists reported that they created this compound by compressing buckyballs -- soccer ball-shaped molecules each made of 60 carbon atoms -- at 2,200 degrees C and 200 times normal atmospheric pressure, a process that could lend itself to mass production. Potential industrial applications for materials made from nanorods include the cutting and polishing of alloys and ceramics.

Carbon was also the material chosen by **Pulickel M. Ajayan** at Rensselaer Polytechnic Institute in Troy, N.Y., and his colleagues to create super-resilient springs. The researchers used a foam made up of carbon nanotubes to devise springs that combine the properties of stiffness and compressibility. Stiff materials take a lot of force to squash but often break after their limits are exceeded, while compressible substances often buckle easily but can rebound to their usual shape afterward with little to no damage. Repeatedly compressing a cushion normally squashes it, with a loss of springiness. But the nanotube foams remained elastic even after 10,000 squeezes, a property that could make the material suitable for artificial joints or vibration dampeners.

At times scientists have drawn inspiration from nature to come up with novel materials. Modern ceramics are strong but brittle, but mollusk shells exhibit strength while retaining intrinsic toughness because of their finely layered mother-of-pearl, or nacre. Replicating the intricate architecture that gives nacre its material properties had proved extremely difficult because the dimensions of its components vary from nanometer to micrometer scales.

Antoni P. Tomsia at Lawrence Berkeley National Laboratory and his colleagues found they could mimic its structure just by freezing a watery suspension loaded with hydroxyapatite, bone's mineral component. They built a multilayered nacrelike material that might find use in artificial bone and joints or in tissue regeneration.

Research that took inspiration from the natural world may also prove useful to the electronics industry, which often requires high temperatures and harsh acids or bases to create thin films of silicon or other semiconductors. **Daniel E. Morse** at the University of California at Santa Barbara revealed in April that by putting enzymes that mimic those of marine sponges onto gold surfaces, his team created templates for growing semiconductor films.

Marine sponges build intricate skeletons with an internal structure made of glass needles by using enzymes known as silicateins that act both as catalysts that assemble the glass and as

physical templates to form the material into needle shapes. Morse and his colleagues developed compounds that, when combined, act like silicateins. They then put them onto gold surfaces to serve as templates to grow semiconductor films on. Inspiration from a lowly marine sponge may eventually yield more powerful batteries and highly efficient solar cells.--*Charles Q. Choi*

Sight Savers

Technology that could help the blind see is now in the laboratory

Conventional wisdom specifies that the central nervous system--the brain, spinal cord and eye--cannot heal in adults. Once injured a patient remains impaired for life. Experiments with animals have demonstrated regrowth of injured nerve fibers. But these techniques often need to be applied at or before injury.

The standard thinking no longer holds. **Larry I. Benowitz** at Children's Hospital Boston and his colleagues found a molecule that triggers better nerve regeneration than any other studied-and one that that proves effective when applied days after injury. The scientists discovered that a protein, oncomodulin, is secreted in damaged eyes by immune cells known as macrophages. They found that oncomodulin, when given with compounds that enhance its activity, can increase nerve regeneration fivefold to sevenfold in rats with injured optic nerves.

Benowitz believes oncomodulin could someday help reverse optic nerve damage caused by glaucoma, tumors or trauma, and plans to investigate whether the treatment could work to help treat stroke and spinal cord injury. Tests have yet to prove whether the compound is effective in humans, but its gene is found in many vertebrate species.

Another invention affords hope that some blind people may be able to view images and video. Visually challenged artist and poet **Elizabeth Goldring**, a senior fellow at the Massachusetts Institute of Technology's Center for Advanced Visual Studies, developed just such a "seeing machine." Created over the last decade, the device costs about $4,000, compared to the $100,000 price tag of its larger, bulkier inspiration. Goldring discovered through her doctor, a scanning laser ophthalmoscope. The instrument projected images directly onto the retina, past the hemorrhages within the eye that contributed to her blindness. (Surgeries have since restored vision in one of Goldring's eyes.)

The desktop-seeing machine replaces the laser of the ophthalmoscope with more inexpensive light emitting diodes, another source of high-intensity light. Goldring and her colleagues reported in February that in a pilot clinical trial of the seeing machine with 10 volunteers, most of whom were legally blind, six correctly interpreted all 10 examples of a visual language Goldring developed consisting of short words incorporating graphics and symbols. The researchers are now working toward a large-scale clinical trial of a color-seeing machine. The device tested in the pilot trial produced black-and-white images.

Prosthetics of another kind may in the future enable an amputee to use electrical signals from remaining muscles so that he or she can move an artificial arm more naturally simply by thinking. The present generation of this technology only allows three kinds of motions -- flexing the elbow, rotating the wrist, and grasping a hand. It generally permits control of just one motion at a time. Also, electrodes in current prosthetics penetrate into nerves, which only detect a limited number of the neurons within a nerve and may cause scarring.

To help develop next-generation prosthetics that can perform up to 22 distinct motions that

better match human performance, **Protagoras Cutchis** at Johns Hopkins University devised an electrode array implanted around the sheath of a peripheral nerve that does not penetrate into the nerve itself. This invention can detect the individual electrical signals from each cell within the nerve to potentially enhance control of the prosthesis. Machines are thus proving ever more able to pick up the slack when humans falter.--*Charles Choi*

Of Brain Maps and Saving the Internet *An array of technologies are complemented by a push toward sensible public policy* **The Ultimate Computer**

Once a theoretical curiosity, the idea of a computer that stores information in quantum superpositions of 0 and 1, known as quantum bits or qubits, is edging slowly toward reality. Demonstrations of simple quantum computation have typically relied on relatively clunky experimental setups that would not easily allow hundreds or thousands of qubits to work together like logic gates on a Pentium processor. This year researchers finally engineered microchips capable of rudimentary storage and manipulation of the quantum states of individual charged atoms, the most promising candidates for implementing practical qubits. **Christopher Monroe** of the University of Michigan in Ann Arbor and **David J. Wineland** of the National Institute of Standards and Technology in Boulder both fabricated chips capable of storing just a few atoms, paving the way for more elaborate chips that can manipulate atoms in more serious numbers.--*JR Minkel*

Net Neutrality

Phone and cable companies have recently begun floating the idea of charging major Internet content providers such as Google and Vonage for "premium" access to bandsize. Outraged at the proposed tampering with so-called network neutrality-the concept that all Internet traffic should be carried and charged for in the same way--consumer groups lobbied the Federal Communications Commission to enshrine neutrality as a regulatory principle. Columbia University law professor **Timothy Wu** has been a leader in articulating and articulating the value of neutrality. Unfortunately, this June the House of Representatives voted down the Network Neutrality Act of 2006, introduced by Edward Markey of Massachusetts, one of several proposed bills to consolidate the principle of network neutrality as law.

DNA Building Blocks

One sub-discipline of nanotechnology devotes itself to building structures with molecules of DNA. Last year at the University of Oxford, working jointly with Vije University in Amsterdam, described using DNA to construct a tetrahedron, a pyramid that has three faces and a base. The rigid structure measures 10 nanometers wide and could conceivably form a building block for electronic circuits that send currents along paths in three dimensions. The technique devised by **Andrew J. Turberfield** allows the fabrication of trillions of these structures in just a few minutes.--*Gary Stix*

Brain Atlas:

Three years ago Microsoft co-founder **Paul G. Allen** donated $100 million to establish the Allen Institute for Brain Science. Its first project would be the Allen Brain Atlas, aimed at accelerating efforts to map where and when every gene in the mouse brain is active. This September the Institute unveiled the complete Atlas, a three-dimensional map depicting the activity of 21,000 genes in time and space and resolved down to individual cells. The map was pieced together by dividing whole mouse brains into thin slices and probing each one to determine what genes were active and where. Because mice and humans share up to 90

percent of the same genes, researchers hope that such a map will provide insights into the genetics of human brain development, functioning and disease, including Alzheimer's, addiction and autism.--*JR Minkel*