A PLAN FOR A BRIGHT FUTURE BEYOND 2050

SCIENTIFIC AMERICAN

SPECIAL ISSUE

SEPTEMBER 2005
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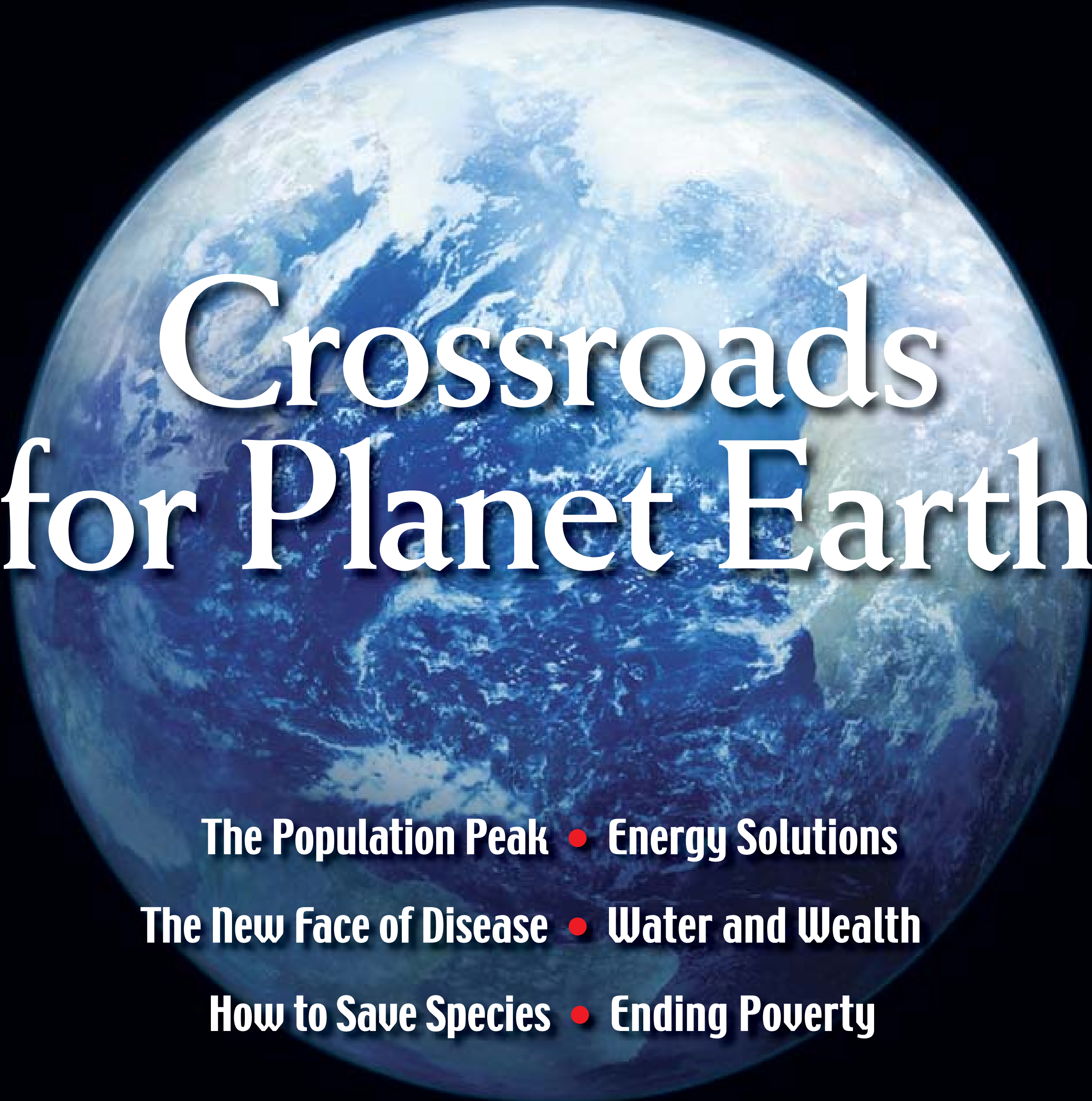
The human race is at a unique turning point.
Will we choose to create the best of all possible worlds?



Crossroads for Planet Earth

The Population Peak • Energy Solutions

The New Face of Disease • Water and Wealth

How to Save Species • Ending Poverty

september 2005

SPECIAL ISSUE

SCIENTIFIC AMERICAN
Volume 293 Number 3

CROSSROADS FOR PLANET EARTH

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Cover illustration by Jean-Francois Podevin

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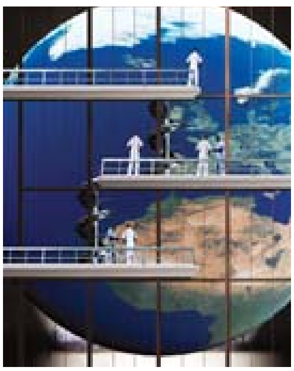
SA Perspectives

Science at the Crossroads

At an environmental science workshop this past spring, Columbia University ecologist Shahid Naeem mused, "Gone are the good old days when you could do ecology just because it was fun." Those in his profession might once have analyzed ecosystems purely for the intellectual challenge, but today their work has an urgency to it. They return to a forest they had worked in, only to find it chopped down; they hear older colleagues reminisce about birds last seen decades ago; they walk on permafrost turned mushy by global warming.



MANAGING Planet Earth is a job that demands scientific advice.

As described in this special issue, the world is now undergoing a remarkable set of transitions: population growth has reached an inflection point and is starting to level off, the developing world is becoming developed, and environmental problems that used to be localized are radiating everywhere. The interconnected changes are, in demographer Joseph Chamie's words, a "quiet revolution" that reaches into every corner of life. They pose threats but also offer opportunities. Having seen firsthand what is happening, the authors of the articles here have thrown themselves into the task of helping society navigate the shoals ahead.

Some people don't like that. They say that the social and environmental sciences already smack of politics and that scientists should steer clear of anything resembling advocacy. These critics claim to be standing up for "real science," yet they define science in a way that most practicing scientists find alien. True, there comes a point when scientists offering advice on political issues act in the capacity of private citizens rather than researchers—and when that happens, they should represent themselves as such. And they do run a risk of letting ideology backwash into their technical judgment. Yet the extreme alternative—disengagement—is not an option. It would be a denial of everything scientists do, an abdication of the responsibility that comes with knowledge.

Scientific American would not even exist without the desire of scientists to reach beyond the confines of their laboratories and help to make the world a better place. Articles on social and environmental sciences, including ones with strong points of view, have filled our pages since the magazine's founding in 1845. On many past occasions—notably in 1974, 1980 and 1989—we have devoted an entire issue to the challenges of balancing economic development with environmental protection.

Some critics, though, are unconcerned with philosophical debates about what scientists should or shouldn't do. Their complaints boil down to: *I don't agree with what you're saying, and rather than engage with it, I will deny your legitimacy to say it.* Sadly, that has become the dominant rhetorical strategy in the country today—one that will only make it that much harder to address the challenges of the coming decades.

Geographer Jared Diamond's recent book *Collapse* documents past civilizations that could not recognize or bring themselves to change unsustainable ways. Largely because of science, our civilization has the chance not only to avoid their fate but to enter an age of unprecedented prosperity. Science is not and should not be the sole factor in decision making; others, such as moral values, are also crucial. But we need to go into these decisions with our eyes open to what is going on in the world.

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High-Tech Pictures Reveal How Hummingbirds Hover

COURTESY OF OREGON STATE UNIVERSITY

Hummingbirds are famous for their hovering ability, which lets them linger in front of flowers to feast on nectar. Just how they manage to stay aloft has intrigued researchers for years. Now a new analysis shows that the creature's flight pattern is halfway between that of a bird and an insect.

Psyching Out Evolutionary Psychology: Interview with David J. Buller

Philosopher of science David J. Buller has a bone to pick with evolutionary psychology, the idea that some important human behaviors are best explained as evolutionary adaptations to the struggles we faced tens to hundreds of thousands of years ago as hunter-gatherers. In his new book, *Adapting Minds*, the Northern Illinois University professor considers—and finds lacking—the evidence for some of the most publicized conclusions of evolutionary psychologists: men innately prefer to mate with young, nubile women, whereas women have evolved to seek high-status men; men are wired to have a strong jealous reaction to sexual infidelity, but women react to emotional infidelity; and parents are more likely to abuse stepchildren than their genetically related children.

Climate Change Could Set Dunes in Motion, Study Suggests

The dunes of Africa's Kalahari Desert may soon be on the move as a result of climate change, scientists say. Research findings indicate that by the end of the century the shifts could have drastic environmental and social consequences in the region.

Ask the Experts

Why do bees buzz?

Gard Otis, a professor of environmental biology at the University of Guelph in Ontario who studies bee behavior, ecology and evolution, explains.

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Letters

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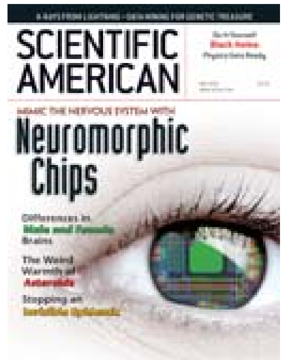


IN THE MAY ISSUE, commentary in "Human Inventory Control" [SA Perspectives] about a California school that made students wear radio identity tags piqued the strongest opinions. Perhaps reflecting the dilemma of freedom versus security we face as a nation, the piece brought out, in roughly equal numbers, readers' authoritarian and libertarian predilections, as well a novel observation on the convenience offered by a surveillance society. As Richard Brunt of Redondo Beach, Calif., writes, "If you are doing what your society has agreed upon, then what do you have to hide? If you are not, then why should that society give you the right to hide that fact? I personally would love an ID-chip implant. It is easier to carry and more difficult to lose than a driver's license or passport—and it would aid in medical emergencies, not to mention ordering drinks while naked in the Jacuzzi." But John Schmitt e-mails a more cautionary note, "In democratic societies, power belongs to the people, and we should parse out only limited powers to the government, or we will face many abuses."

X AND Y BRAINS

Psychological research has found several reasonably well verified differences between genders ["His Brain, Her Brain," by Larry Cahill]. Aside from differences in reproductive roles, however, these disparities are statistical, meaning that distinctions occur in averages but that the distributions for genders overlap. For example, the accepted generalization that "men are stronger than women" is a statistical difference: some women are stronger than some men.

Cahill does not state whether the distinguishing features between men's and women's brains are categorical, such as those connected with reproduction, or statistical, such as those linked with strength. This fact is important, because medicine and society need to recognize the nature of the gender divergence. For instance, men may perform better as combat soldiers than women as a result of their temperament and physical abilities, but because these differences are statistical, it is also true that some women can be good combat soldiers, whereas some men cannot. Hence, it would be as much of an error to assign only men to combat as it would be to use different standards for each gender so that equal numbers are selected for combat roles.

Kellogg Wilson
St. Albert, Alberta, Canada

Cahill reports differences in the means of some brain characteristics by sex. I was wondering if he could say something about the extent to which the distributions overlap. I have always thought that were we to find some "statistically significant" difference on some measure by sex (or race, or whatever), the degree of overlap of its distribution would most likely lead to the conclusion that it does not matter for most practical purposes.

Brian Easton
Wellington, New Zealand

CAHILL REPLIES: The differences found in the research I described were all of a statistical nature, as is typical in neuroscience, and were significant. The extent of overlap between groups was also like that found in any other area of neuroscience.

Cahill suggests that gender differences might have to be taken into account when researching drugs aimed at brain disorders. This is exactly what happened to the Upjohn Company in the 1970s and 1980s, when it was developing a steroid drug that halted the lipid peroxidation damage to brain tissue caused by bleeding after a stroke. The drug worked very well in men but not in women. Upjohn sank about 10 years and tens of millions of dollars into the development of the drug but came away with nothing.

Dennis Weber
Upjohn Drug Metabolism Research (retired)
Kalamazoo, Mich.

INFORMATION QUEST

I am intrigued and encouraged by Andrey Rzhetsky's GeneWays medical literature mining software ["Molecular Treasure Hunt," by Gary Stix]. I disagree, however, with Stix's statement that the software will most likely never replicate a human's ability to parse medical literature. There are several challenges to be addressed prior to elevating GeneWays to the (imperfect) level of human work. The software must have the ability to handle all forms of negation appropriately. It must also account for publication bias in which "negative" or "uninteresting" results are not published or even submitted for publication and as well must deal with multiple publications that yield conflicting results.

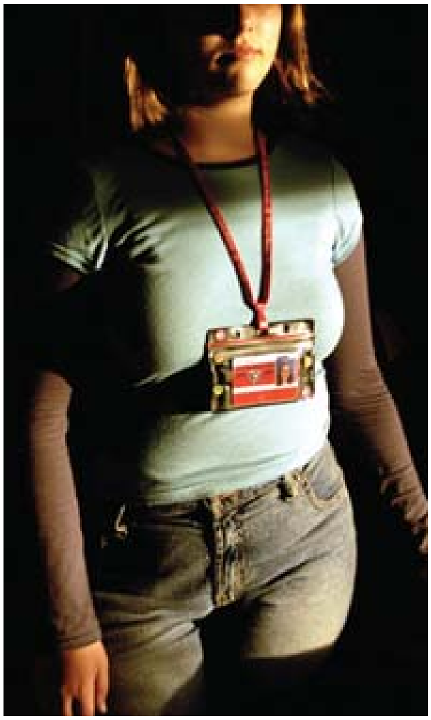
Distinguishing authors' conjecture from experimental fact is also crucial, in that scientific results are not always definitive and authors may propose several hypothetical explanations for the observed data. Established methods exist to approach these challenges. I suspect that GeneWays may in fact surpass our ability to read and integrate diverse sources of scientific information.

Asher Schachter
Children's Hospital Informatics Program
Boston, Mass.

CHIPPING AWAY AT PRIVACY

In "Human Inventory Control" [SA Perspectives], you say human-tracking devices shouldn't be embraced without a great deal of discussion, but does anyone really doubt that they will eventually be accepted and commonplace? Regardless of the issues, the current trend in our government will be to invoke fear that will convince people to give up more of their privacy. Oh, we'll be given lots of great reasons to embrace human tracking—finding lost children, tracking terrorists, caring for Alzheimer's patients—but the real reason will be to give more power to those who enjoy controlling and intruding in our lives. The "discussion" will be a slow but relentless campaign from "if" to "when" to "how to do it."

Harry S. Delugach
Huntsville, Ala.



TAG, YOU'RE YOU: **Student sports a radio-tag identification badge.**

Help me. Just what is so scary about being able to prove that people are who they say they are (or not)? If you want to remain anonymous, then stay home. But if the technology exists to readily identify everyone, then no one's identity can be stolen. Mistakes? Maybe. The consequences don't seem near so dire, however, as the mistake of cashing a check for a crook, allowing a person to vote more than once, admitting a pedophile into a day care center, selling a firearm to a known criminal or hiring someone who is certifiably insane.

Noel Funchess
Cleveland, Miss.

RED STATES VERSUS GREEN STATES

There is something seriously amiss with the map in "Measuring Beauty," by Rodger Doyle [By the Numbers], which rates U.S. counties on desirable natural qualities. Without disrespect to Kansans, for example, much of the Great Plains lacks geographic amenities yet is in yellow (the middle six deciles), whereas areas in northern Wisconsin, filled with forests, lakes and hills, are red (the bottom). The plains have their own unique beauty, but few people would suggest, as this map does, that northern Wisconsin is not as rich in natural amenities.

The article also states that even when January temperatures are not factored in the map changes little. I would suggest that it is only those temperatures that prevent areas such as Wisconsin's Chequamegon-Nicolet National Forest from being green (the top decile). Population in these areas remains low because of the lack of jobs and harsh winters, not because they lack beauty. Based on the results, I seriously doubt that the USDA's formula can adequately measure such intangibles as beauty or desirability, even if it took more variables into account.

Thomas Rowe
Stevens Point, Wis.

ERRATUM In "Thin Is In," by Mark Fischetti [Working Knowledge], plasma and LCD flat-panel television screens were stated to be about eight inches in thickness. Most range from three to five inches thick.

CLARIFICATION In "Cooping Up Avian Flu," by Christine Soares [News Scan], influenza is described as typically having a low "reproductive number," which is the average number of new infections one infected person will cause. An example given was the highly infectious 1918 pandemic flu strain whose reproductive number of 2 to 3 was higher than normal seasonal influenza but still low compared with a disease such as measles, which has a typical reproductive number of 16 to 18.

MAX WHITTAKER *AP Photo*

50, 100 & 150 Years Ago

FROM *SCIENTIFIC AMERICAN*

Observing Earth ▪ Diverting Water ▪ Girdling the World

SEPTEMBER 1955

GEOPHYSICAL EARTH—"The historic decision of U.S. scientists to attempt to launch an artificial moon within the next three years is a symbol of man's increasing ability to view the earth as a whole. This ability is also expressed in plans for an International Geophysical Year, for 1957. The frontispiece of this issue shows a man holding a Polynesian navigation map representing a region around the Marshall Islands. Behind the map is a globe devised in about 145 B.C. by Crates of Mallus of the Stoic school. The globe divides the earth into four quarters separated by oceans. It thus poetically anticipates the discovery of North and South America and Australia."

TRUE NORTH—"In the past few years it has become possible to read the magnetic record for millions of years by means of certain natural compass needles which nature has frozen into the rocks. Reading these magnets in rocks at various places around the world, we find evidence of astounding changes in the earth's main axial field. During the Tertiary period (between 60 million and one million years ago) the north and south geomagnetic poles reversed places several times! —S. Keith Runcorn"

CONTINENT GUESS—"It seems that in the beginning all was ocean, from which the continents began to rise as small islands. Perhaps stresses upon the surface of the original whole-ocean earth caused it to buckle, producing troughs, ridges, folds and fissures. Weathering by the oxygen-rich atmosphere may then have segregated the more acid material of these ridges in sediments. The silicic [granitic] sediments, deposited along the edges of the raised lands, would have formed the first sialic areas on the earth."

SEPTEMBER 1905

SCARCE WATER—"Apart from the fact that it was Bunker Hill Day, June 17, 1905, was an occasion of great moment to the interest of the State of Nevada, for then it was that the immense government irrigation canal known as the Main Truckee Canal received its first water from the Truckee River. The Indians will not suffer, even though Pyramid Lake does dry up on account of its main artery, the Truckee River, being diverted from it into the irrigating canals. When the lake runs dry, if it ever does, the Indians will have water from the irrigating system. Therefore there is no cause for alarm over the care of the Indians in the event of the Pyramid Lake drying up." [*Editors' note: In 1968 the Paiute Indians, alarmed by Pyramid Lake drying up, initiated a series of lawsuits to reverse the process.*]

SCIENTIFIC AMERICAN

EARTH, Polynesian map and ancient Greek globe: frontispiece of single-topic issue on geophysics, 1955

SEPTEMBER 1855

MORSE GOLD—"The Emperor of Austria has conferred upon Professor Morse the large golden medal for arts and sciences, in consideration of the valuable services rendered by his system of telegraphs, which has been extensively applied in the Austrian dominions. Scarcely twelve years have elapsed since Professor Morse's first public experiment in Electric-Telegraphing was made between Baltimore and Washington. Now there are about fifty thousand miles of the wires in operation, and they stretch under seas and over mountains, into almost every part of the habitable globe. Nearly as many miles more are in progress of construction. The Electric Telegraph is the wonder of our age."

ATTENTION, INVENTORS—"We shall take occasion to give a delicate hint of caution to inventors, upon the subject of Marble Saws. Since Mr. Manly's liberal offer of $10,000 for the best sawing machine, the inventive world appears to have gone all agog on the subject. There seems to have suddenly arisen a very general opinion that there never was such an easy task set before a man, as to carry off this prize. Our remarks are not intended to discourage any one; but to make them think harder and observe closer. All the more primitive ways of arranging the saws have been invented. There is ample time and room for the display of real ingenuity."

news SCAN

ENVIRONMENT

Mapping Mercury

HOT-SPOT UNKNOWNS COMPLICATE MERCURY REGULATIONS **BY REBECCA RENNER**

In issuing the Clean Air Mercury Rule this past March, the Bush administration hoped to ease health concerns about mercury from coal-fired power plants. The White House enacted a "cap and trade" approach to reduce emissions of the element nationwide by about 20 percent in five years and 70 percent by 2018. In formulating its rule, the administration noted that power plants emit only 48 tons of the metal every year—just a small fraction of the total amount of mercury in the atmosphere. Mandating further emission cuts, it argued, would not solve the problem of human exposure to the neurotoxin.

METALLIC SPREAD: Distinct environmental conditions help to amplify local concentrations of methyl mercury, leading to health warnings such as this one in the Florida Everglades.

DAVE G. HOUSER *Corbis*

Eleven states and four public health groups are challenging this approach, arguing that cap-and-trade does not address areas particularly vulnerable to mercury pollution. Not so, says the Environmental Protection Agency. When the cap-and-trade proposals were announced, the EPA's head of air regulations, Jeffrey Holmstead, said, "We don't think there will be any hot spots." The hot-spot standoff arises from big gaps in mercury science, according to environmental researchers, and the lack of comprehensive data on mercury deposition means that a consensus about emissions control will not likely emerge soon.

Theoretically, mercury should preferentially rain down in areas near to power plants. But attempts to determine the fallout have proved incomplete. For instance, the Mercury Deposition Network, which measures the metal in rainwater in many parts of the country, does not account for mercury particulates that settle dry onto vegetation, a form of deposition that could be equal to the wet variety, according to Oak Ridge National Laboratory scientist Steve Lindberg.

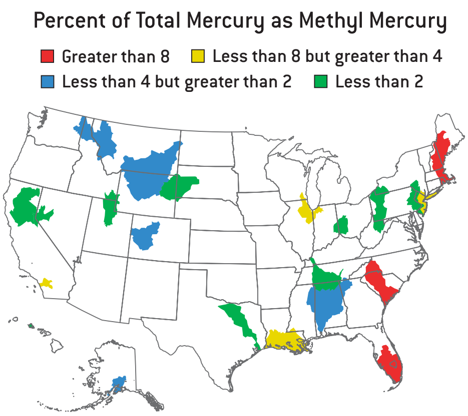
And just because a region receives above-average deposition doesn't mean that it will

MERCURY'S TIME TO FALL

The Bush administration argues that mercury from power plants is a small fraction of that already in the atmosphere. The comparison is misleading, argues Praveen Amar, science director for NESCAUM, an association of air-quality regulators in the northeastern states. That's because most of the mercury in the atmosphere is in a gaseous elemental state that remains there for about a year and should not be a major contributor to rapid changes in mercury deposition. On the other hand, about 50 percent of the mercury emitted by power plants is oxidized mercury that rains down within a few days, he says.

Many mercury scientists agree, but it is hard to prove. The best evidence comes from recent EPA monitoring of Ohio Valley power plants. It showed that the depositions of oxidized mercury and sulfur dioxide, a tracer for combustion, increase together, and back trajectories based on meteorological data implicate the plants.

have high levels of methyl mercury, the form that builds up in long-lived predatory fish such as trout, pike, tuna and swordfish. "The areas with the most problems may not have the highest levels of deposition," explains mercury expert David Krabbenhoft of the U.S. Geological Survey branch office in Middleton, Wis. Indeed, the Southeast



HOT SPOTTING: Measurements reveal areas that readily convert mercury to methyl mercury.

has greater measured deposition than the Northeast, but both regions have serious methyl mercury problems.

A partial explanation for this dichotomy is the process by which elemental mercury becomes methyl mercury. For mercury to get methylated and enter the food web, it must be processed by bacteria that thrive on sulfate, a sulfur compound. This means that dissolved organic matter and sulfur enhance methylation, as do acidic waters such as those in the Northeast. The methylation process changes the conclusions drawn simply from examining mercury fallout. For instance, Krabbenhoft recently completed a study of New England lakes from locations near Boston and up to Maine. Mercury emissions and deposition are highest in the urban area, but methyl mercury in fish is low. The fish problems occur in Vermont and New Hampshire, where the conditions are right for methylation. "What do we want to protect?" he asks. "If it's beautiful fishing spots like these lakes, then we need to look at more than deposition."

Scientists finally understand methylation well enough to map out vulnerable areas at a national level, according to Krabbenhoft, who is currently working on such a map for the EPA. The work should, for the first time, combine deposition and vulnerability to identify unambiguous hot spots—regions where it makes the most sense to take action to limit the effects of mercury. Scientists hope that this information and other advances may resolve the hot-spot debate and demonstrate the wisdom or folly of the administration's approach to mercury regulation.

Rebecca Renner is a writer based in Williamsport, Pa.

MELISSA THOMAS; SOURCE: U.S. GEOLOGICAL SURVEY

REMEDIATION

Blue-Green Acres

FIGHTING FACTORY CO_2 EMISSIONS WITH CYANOBACTERIA **BY PATRICK DI JUSTO**

What do you get when you put polluted water, fossil-fuel exhaust, sunlight and heat-loving green slime into a metal box? If the box belongs to David Bayless, you get pure oxygen, clean water and a potential means to remove greenhouse gases from the atmosphere.

Bayless, director of Ohio University's Ohio Coal Research Center, thinks that the easiest way to eliminate the carbon dioxide given off by coal-burning power plants is nature's way, through photosynthesis. But industrial quantities of CO_2 need industrial amounts of photosynthesis. So, with the help of a Department of Energy grant, Bayless came up with a scalable box packed with photosynthesizing cyanobacteria (blue-green algae).

In Bayless's bioreactor, algae grow on 60- by 120-centimeter membranes of woven fibers, which resemble window screens. Capillary action wicks water to the algae, and ducts bring in the hot flue gas. By spreading the cyanobacteria on membranes, "you get a lot of surface area for growth, but you don't need a lot of water," Bayless explains. The algae use the available CO_2 and water to grow new algae, giving off oxygen and water vapor in the process. The organisms also absorb nitrogen oxide and sulfur dioxide, which contribute to acid rain.

Because the flue gas and water enter the bioreactor at a toasty 55 degrees Celsius, Bayless needed a hardy species of algae. "We were very much against genetic manipulation for this project, because we were going to be generating such very large quantities of algae," he remarks. To find the right bacterium, Bayless contacted Keith Cooksey, a microbiologist at Montana State University who had been researching bacteria found in the mineral hot springs of Yellowstone National Park. "We took some of David's membrane screens and stuck them in a hot stream just outside of Yellowstone," Cooksey explains. "Whatever bacteria stuck to the membranes we knew was a good bet." The best candidate was a newly discovered iron-loving cyanobacterium, which he tentatively named *Chroogloeocystis siderophila*.

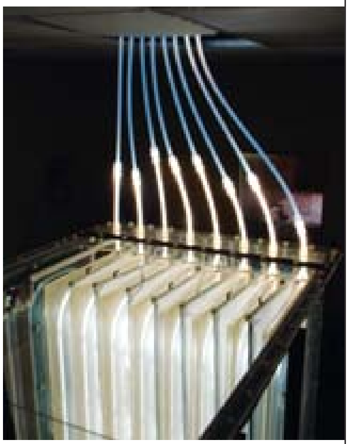
To spread a little sunshine inside the bioreactor, Bayless turned to the scientists at Oak Ridge National Laboratory. They had developed a system using parabolic mirrors to collect sunlight and channel it along plastic fiber-optic cable. Ordinarily used to provide office or factory lighting, the Oak Ridge system was modified to use "glow plates," slabs of acrylic plastic that emit sunlight directly onto the bioreactor's algae screens. "The bacteria use only about 10 percent of full-strength sunlight," says Oak Ridge's Duncan Earl. "This enables us to take one square meter of sunlight and spread it out over 10 square meters of glow plates."

One big problem is what to do with the huge quantities of algae the bioreactor produces; *C. siderophila* might constitute an invasive species if released outside of Yellowstone. "That's definitely one of the drawbacks," Bayless admits. Current plans call for automatically hosing off and collecting the excess algae, which might be used as fuel.

The idea of algal photosynthesis to fight pollution is not new. GreenFuel Technologies in Cambridge, Mass., has been testing 30 bioreactors on the roof of a gas-oil 21-megawatt power plant at the Massachusetts Institute of Technology. Its method also relies on natural sunlight, but with a twist: instead of moving the sunlight to the algae, GreenFuel rotates the algae in and out of the sunlight, a process called photomodulation, explains GreenFuel co-founder Isaac Berzin. Bayless likes his fiber-optic system better, however, because it has a smaller "footprint," needing only a tenth of the sunlight.

Right now Bayless has a prototype handling 140 cubic meters of flue gas per minute, equivalent to the exhaust from 50 cars or a three-megawatt power plant. If a test using a Tennessee Valley Authority power plant works, Bayless hopes to have a full-scale bioreactor, with 1.25 million square meters of algae screens handling the output of a 10-megawatt power plant, running by 2010.

Patrick Di Justo writes about science and technology from New York City.



GLOW PLATES, lit by the channeling of sunlight via fiber optics, provide a light source for algae, which would be placed on screens between the plates.

NEED TO KNOW: MOP-UP DUTY

Besides getting bacteria to eat up factory flue gases, scientists have also enlisted microbes to:

- Neutralize industrial hydrogen peroxide
- Clean chlorinated solvent spills
- Sequester uranium from groundwater
- Break down oil released into the environment

INFOTECH

Flagging Copy Rights

PIRACY PROTECTION MAY REDEFINE HOME RECORDING BY WENDY M. GROSSMAN

The right to protect against unauthorized copying of digital television and film seemed to take a step back for the entertainment industry and content provider—and a step forward for the consumer and video pirate—when a federal court struck down the planned July 1 introduction of the "broadcast flag." The flag is a set of bits in a digital transmission that can prevent recording. But advocates of free recording are not celebrating the defeat of the flag—transmissions standards currently being devised could trump the ruling.

The consortium creating the standards

is the Digital Video Broadcasting (DVB) Project, a group that includes broadcasters, mobile phone companies, set-top box manufacturers and movie studios. Most of its work defines ways to transmit, encode and format data. But the next version of the DVB standards will include a scheme called Copy Protection/Copy Management (CPCM), which, if implemented, may give copyright holders even more control than the broadcast flag would have.

As drafted, CPCM will allow them to specify, for example, whether protected content can be copied—and, if so, onto how many devices. They could dictate how many times a program can be viewed, where it can be viewed and how long a copy may be kept. While attending a public DVB Forum meeting held in Dublin this past March, Jim Williams, vice president of the Motion Picture Association of America, said in private that preventing someone from accessing a single HBO subscription from two different locations is "social justice."

The basis of CPCM is the "authorized domain," which is loosely congruent to a household. Once started, a CPCM-compliant device, say a video recorder, will look around for other CPCM devices. If it does not find any, it will create a new domain. If it finds one or more, it will negotiate a series of tests before joining the domain.

Commercial content from a broadcast, data stream or shrink-wrapped medium will be housed in metadata that specify how the content may be used. Disney's Chris Hibbert, chair of the DVB's copy protection effort, also explained at the Dublin DVB meeting that a copyright holder can specify whether the content may be exported to non-CPCM devices.

The power that CPCM would grant copyright holders dismays the Electronic Frontier Foundation, which has joined the DVB to represent consumers while the specification is being drafted. The group, which lobbies for the extension of civil liberties into cyberspace, has long opposed recording restrictions on the basis of fair use and the importance of public access to culture. Cory Doctorow, the EFF's European Outreach Coordinator, argues that CPCM "gives the studios a veto over what constitutes valid use of copyrighted works, valid design of devices, and even (through the 'authorized domain') valid family arrangements." He adds: "Copyright is supposed to give you control over who copies your works, not who can build devices."

Right now digital content can escape protection through analog outputs, and the Federal Communications Commission seems willing to keep that door open, based on its 2003 rejection of a feature called selectable output control that would have blocked the signal. But CPCM in a worldwide technical standard could render such decisions irrelevant. Complains Doctorow: "The intention is to have legislators say, 'The law is that DVB is the law.'"

Wendy M. Grossman writes frequently about computer and information technology from London.

RECORDING RIGHTS AND WRONGS

Home video recording would not exist today without the 1984 U.S. Supreme Court decision in *Sony v. Universal*. In a five-to-four decision, the court ruled that video recorders had sufficient noninfringing uses, so that Sony could not be held liable for copyright infringement committed by Betamax owners. It effectively legalized the VCR and gave consumers the right to time-shift television viewing. The recent Supreme Court decision in the Grokster case modifies the 1984 decision but does not overturn it: the court ruled that makers of technologies could be held liable for users' copyright infringement but only if they promoted such uses.

CULTURE

Clash in Cambridge

SCIENCE AND RELIGION SEEM AS ANTAGONISTIC AS EVER BY JOHN HORGAN

In the very first lecture of the Templeton-Cambridge Journalism Fellowship in June, a University of Cambridge biologist assured the 10 journalists in his audience that science and religion have gotten along much better, historically, than is commonly believed. After all, scientific pioneers such as Kepler, Newton, Boyle and even Galileo were all devout Christians; Galileo's run-in with the Church was really a spat between two different versions of Catholicism. The notion that science and religion have always butted heads is "fallacious," declared Denis Alexander, who is, not coincidentally, a Christian. Other lecturers, who included four agnostics, a Jew, a deist and 11 Christians, also saw no unbridgeable chasm between science and their faith.

WORLDS APART? Biologist Richard Dawkins (*left*), an agnostic leaning toward atheism, explains his reasoning to philosopher Nancey Murphy, a materialist who also adheres to nonscientific ideas, such as the resurrection of Christ.

JULIA VITULLO-MARTIN

As the two-week meeting unfolded, however, conflict kept disrupting this peaceable kingdom. Lecturers and journalists argued over a host of questions: Without religion, would humanity descend into moral chaos? Are scientific claims in some sense as unprovable as religious ones? Can prayers heal, and if so, is that evidence of the placebo effect or of God's helping hand? Why does God seem to help some people and ignore others? By the end of the conference, the gulf between science and religion—or at least Christianity—seemed as wide as ever.

Take the exchange between biologists Simon Conway Morris of Cambridge and Richard Dawkins of the University of Oxford. Morris contended that intelligence is not a freak occurrence but a recurring theme in evolution, appearing in dolphins, parrots and crows as well as in primates. He speculated that any of these species might be capable of discovering God, but we had help—from Christ, whom God sent to Earth for our benefit. Dawkins, by far the most antireligious lecturer, praised Morris's evolutionary views but called his Christianity "gratuitous." Morris retorted that he found Dawkins's atheism "archaic" and asserted that the resurrection and other miracles attributed to Christ were "historically verifiable." After more give-and-take, Morris, crossing his arms tightly across his chest, grumbled, “I’m not sure this conversation can go any further.”

Dawkins also challenged the faith of physicist John Barrow, an Anglican. Like several other speakers, Barrow emphasized how extraordinarily “fine-tuned” the universe is for our existence. Why not just accept that fine-tuning as a fact of nature? Dawkins asked. Why do you want to explain it with God? “For the same reason you don’t want to,” Barrow responded drily. Everyone laughed except Dawkins, who protested, “That’s not an answer!”

Disagreement divided believers as well. Physicist John Polkinghorne, a winner of the $1.4-million Templeton Prize, given annually to those who “advance spiritual matters,” contended that physicists’ understanding of causality is “patchy” and hence allows for a God who answers prayers and carries out the occasional miracle, such as parting the Red Sea. Another physicist and Templeton Prize winner, Paul Davies, discerned tentative evidence of design in the laws of nature but added, “As a physicist, I feel very uncomfortable with a God who intervenes” in human affairs.

Tension was evident not only between speakers but also within individual minds. Nancey Murphy, a philosopher at the Fuller Theological Seminary in Pasadena, Calif., described herself as a materialist who does not view the soul as a “spirit” separate from the body. Yet she believes in phenomena that many scientists might find hard to swallow, such as the resurrection of Christ and, at the end of time, of all humans. When a journalist pressed her to explain how resurrection might work, Murphy acknowledged that at times the discussion between science and religion “breaks down” because they involve “incommensurable schemes” for understanding reality.

Peter Lipton, a Cambridge philosopher, spoke of his struggle to be a practicing Jew in spite of his lack of belief in a supernatural God. “I stand in my synagogue and pray to God and have an intense relationship with God, and yet I don’t believe in God,” Lipton confessed with a rueful grin. He compared his religious experience with that of someone who gets pleasure and meaning from a novel even though he knows it is not literally true. "Are you having your cake and eating it, too?" asked journalism fellow Shankar Vedantam of the *Washington Post*. "I'm certainly trying to," Lipton replied.

Half the journalists considered themselves religious, at least when the fellowship began. By the end, the infidels were all holding firm, while at least one believer's faith was wobbling because of the arguments of Dawkins.

Whether the program was all that its sponsor, the Templeton Foundation, hoped for is unclear. Created by investor Sir John Templeton in 1987, the foundation has spent $225 million on publications, conferences and other programs aimed at finding common ground between science and religion. The participants here may not have found that common ground, but they all agreed that spending two weeks on the River Cam pondering the meaning of life—or lack thereof—was jolly good fun.

John Horgan, former senior writer at Scientific American, *is author of, most recently,* Rational Mysticism: Spirituality Meets Science in the Search for Enlightenment.

SENSORS

Silicon Sniffer

DIME-SIZE DETECTOR TO FIGHT BOMB ATTACKS BY STEVEN ASHLEY

Shortly after terrorist bombs ripped through central London's transit system on July 7, Scotland Yard dispatched trained sniffer dog teams to search for explosives and to scent out clues at the blast sites. Meanwhile, less than an hour up the M11 highway in Cambridge, engineers Billy Boyle, Andrew Koehl and David Ruiz-Alonso were lamenting the fact that the antiterrorist technology they had worked on since just after 9/11—a sensitive but inexpensive electronic nose—had not been ready to help avert this tragedy. The Ph.D. engineers have developed a button-size chemical sensor prototype that is designed, among other things, to detect trace amounts of explosives before they detonate.

The prospect of a modern-day coal-mine canary for trains and buildings still lies in the future for the entrepreneurial brain trust of Owlstone Ltd., the University of Cambridge spin-off company the trio established two years ago. But backed by $2 million in venture-capital funding, the device should be ready for field tests this fall. The three are confident that the low-power device can quickly identify tiny concentrations of substances in parts per billion. "Our idea is to put one on the lapel of every soldier and in every Tube carriage," Boyle states.

The R&D effort started in late 2001, when Koehl, an electrical engineer, arrived at Cambridge from the California Institute of Technology. "From the beginning, I had the idea to create a small, cheap chemical detection system for the military and Homeland Security and then, later, for commercial markets," Koehl says. He soon met Boyle and Ruiz-Alonso, and during the next months, the engineers looked at a lot of sensor technologies, "trying to evaluate what we could take to the next level," Boyle reports.

A chemical sensor "is essentially a filter device," Boyle explains. "Each substance has its own signature smell or fingerprint. That's what we filter out." For Owlstone's sensor, the team chose to develop a relatively new and little known analytic technique called high-field asymmetric waveform ion mobility spectrometry (or FAIMS). The approach sorts compounds according to how their charged forms—chemical ions—move through a gas when subjected to electric fields.

As the ions are made to pass between charged metal plates, varying electric fields (that is, the asymmetric waveforms) drive them toward either side and back again successively, eventually causing most of the ions to hit the plates. But careful application of direct-current voltages to the plates keeps targeted molecules from hitting the sides until they reach a detector at the end. Each DC voltage correlates to an ion type, so the device can be "tuned" to detect specific substances.

Boyle likens the process to "trying to balance several marbles on a sheet of cardboard. Think of the different-size marbles as different ions." Only the right rocking movements—the DC voltages—will keep the largest marbles on the sheet. The separation of ions occurs within only tens of millimeters. Conventional ion mobility spectrometers, the current standard detection technology, are the size of a shoebox or larger because they typically use bigger sensors and a pump to move air between the plates.

Advanced FAIMS sensor technology, which is being pursued in an alternative form by a Massachusetts-based company called Scionex as well as large sensor makers, can also be more selective than conventional detectors. To many standard machines, the "smellprint" of the deadly nerve gas sarin resembles that of common diesel fuel. "With FAIMS, we can simply apply a higher voltage" to distinguish between the two, Boyle notes.

The Owlstone sensor also has many nonsecurity applications—say, as a household fire detector that can discern precombustion products formed before the flames start. It could also work as a sophisticated breath analyzer to identify volatile compounds generated by disease (for example, acetone can be used to monitor diabetes). Antiterrorism and military applications, though, remain the focus for the engineers. Says Boyle: "We hope that one day we'll be sitting on the Tube, look up to see one of our sensors, and know that everybody there is safe because of something we did."

ELECTRONIC NOSE JOB

The key to the small size of the chemical sensor developed by Owlstone in Cambridge, England, lies not only in the ability to miniaturize the particular chemical analysis technology used (called FAIMS) but also in the fact that the engineers relied on standard semiconductor and microelectromechanical technology to build the entire system on a single chip. Thus made, the button-size sensors should be cheap and robust enough to be installed throughout a train, for example. Owlstone expects to be able to make them for less than $5 apiece, whereas standard handheld detectors cost anywhere from $10,000 to $15,000 and as much as $55,000 for an airport model.

BIOTECH

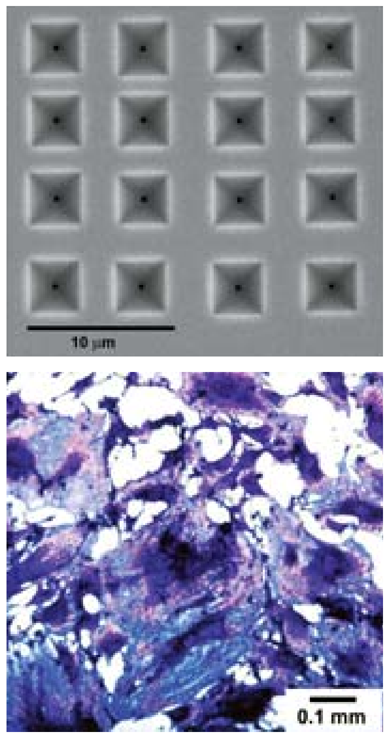
Chatting Up Cells

NANO RESERVOIRS ON A CHIP TELL STEM CELLS WHAT TO DO **BY CHARLES Q. CHOI**

Stem cells can transform into whatever cell the body tells them to. Unfortunately, scientists have yet to master that particular gift of gab. But investigators at Stanford University may soon crack the language with tiny "chat rooms" for stem cells.

In their natural milieu, stem cells have a variety of neighbors that pass on chemical messages at exact spots at particular times in specific amounts to guide the cells' development into a given cell type. In today's laboratory, however, researchers often bathe the whole cell with chemicals—kind of like out-of-control beer keggers compared with the sophisticated cocktail parties the body normally throws for stem cells.

To uncover the mostly unknown placement, timing and identity of the cues, Stanford materials scientist Nicholas A. Melosh and his colleagues are re-creating the niche where stem cells normally dwell. They are developing a microscopic lab on a silicon chip that surrounds a stem cell with as many as 1,000 cavities, each 500 nanometers wide. The nano reservoirs each hold roughly an attoliter (10^{-18} liter) of liquid—comparable to the size of cellular secretions—and are sealed with the same type of lipid bilayer that makes up cell membranes. Tenths of a volt open pores in these layers, so that "when researchers want to deliver a specific chemical to the cell at a particular stage in its development, they will merely have to press a button," Melosh remarks. The team is now working to grow stem cells derived from adult fat.



SILICON ARRAY of cavities (*top*) can be shrunk to nanometer scale, with the hope that stem cells will grow in the pockets. Stem cells seem unfazed by silicon and spread quite readily over the substance (*bottom*). The cells are stained purple.

NICHOLAS A. MELOSH *Stanford University*

In addition to growth factors, scientists could try alternative means to direct stem cells, adds Richmond Wolf, director of technology transfer at the California Institute of Technology. He points to suppressing gene expression using RNA interference.

Melosh also hopes to use their invention to grow tissues from stem cells, layer by layer. This ability could permit the growth of compound tissues that are, for instance, bone on one side and cartilage on another. "Right now if you tear cartilage, you have to screw it back on. There is no way yet to reproduce that interface between bone and cartilage," Melosh states. The hope is to build composite tissues where the artificially grown cartilage naturally bonds with the body's.

A concern is that the chemicals in the nano reservoirs could react with the lipids. So the researchers hope to replace the lipid seals with nonreactive gold ones, which they can dissolve with electric current, if necessary. The voltages used to open seals could also affect the stem cells, but Melosh explains they could solve this problem by recessing the pores so that the electric fields are more distant from the cells.

Standard electronics industry manufacturing can fabricate the device so that it could make it to market in five to eight years, Melosh predicts. But he and colleagues will use it for experiments well before then. "I could see research-level products being used by the beginning of next year if all goes well," Wolf adds.

Charles Q. Choi is a frequent contributor.

PROBLEM OF PUSH AND PULL

The Stanford chip that chemically talks with stem cells could face a problem if stem cells also rely on other cues for their proper development, such as mechanical pushes and pulls or proteins affixed onto neighboring membranes. Nicholas A. Melosh, the lead researcher developing the chip, says that he could readily simulate membrane-bound proteins by stamping the inside of the device with the appropriate compounds. But the chip currently has no good way of generating mechanical cues. Still, it is not clear whether all or most stem cells require them—a question the device could help answer, Melosh says.

BY THE NUMBERS

Myths of the City

PROBLEMS OF URBANIZATION ARE MOSTLY FALSE STEREOTYPES BY RODGER DOYLE

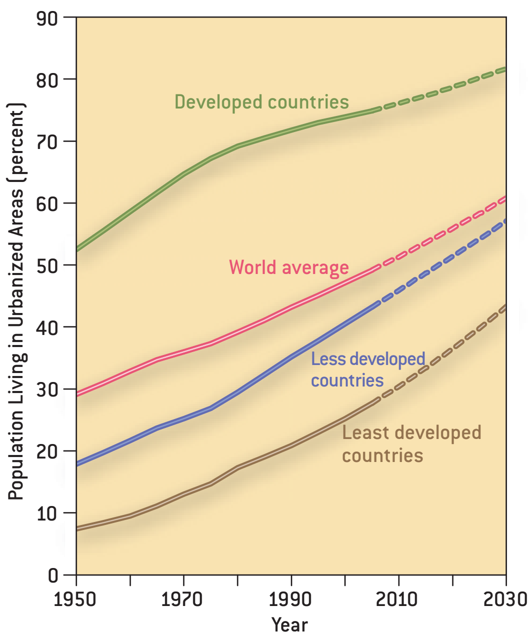
From the beginning of the Christian era to about 1850, the urban population of the world never exceeded 7 percent. The Industrial Revolution quickly changed that—today 75 percent of people in the U.S. and other developed countries live in cities, according to the United Nations.

As the chart shows, urbanization in the developing countries (such as China and India) and the least developed countries (such as Ethiopia and Bangladesh) has long lagged behind that of the West and Japan. Early in the 20th century probably no more than 5 percent of the population in European colonies clustered in cities. But since then, the proportion in these ex-colonies and the never-colonized nations has increased twice as fast as that of the West. New York City, for instance, took about 150 years to add eight million, but Mexico City added 16 million in just 50 years. Such extraordinary growth has exacerbated the usual problems of development, making it difficult to supply drinking water, sewage disposal, police protection and other amenities. The comparatively slow pace of European urbanization was partly the result of 45 million or so people emigrating to the New World rather than moving to cities.

An enduring myth is that the country is healthier than the city. Historically that was true, but no longer. Urban sanitary measures and ready access to good medical care have made the cities healthier. Another myth is that city people are isolated. But a study by sociologists Katherine J. Curtis White and Avery M. Guest of the University of Washington found no disparity in the strength of social ties.

Most of the ills ascribed to urbanization stem from population growth, industrialization and prosperity, which would continue to cause economic dislocation even if urbanization were reversed. Many problems reflect rapid growth rather than numbers of people per se, and in some developing countries, such as China, the wretched condition of factory workers can be blamed on lack of social justice, not the growth of the city.

Manufacturing productivity increases with metropolitan size in part because of publicly funded streets, highways, gas, water, sewerage, power grids, and police and fire stations. Economy of scale makes urban services relatively cheap. Indeed, megacities contribute disproportionately to national economies, as in the case of São Paulo, which has 10 percent of Brazil's population but contributes at least 25 percent of the net national product.



SOURCE: World Urbanization Prospects. *United Nations. Solid lines are estimated; dotted lines are projections.*

The U.N. forecasts a continuing increase in world urbanization over the next quarter of a century to 61 percent (see also "Human Population Grows Up," by Joel E. Cohen, page 48). If the developing countries match the record of the West and Japan, the world will eventually reach a level of over 80 percent. New data from the Earth Institute at Columbia University show that there is more than enough room for expansion: urban areas now cover only 3 percent of the planet's land surface.

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RODGER DOYLE

DEFINING CITIES

The growth of cities as plotted in the chart is based on the United Nations definition of "urban." Generally, nonagricultural settlements with populations as small as 3,000 to 5,000 are included, although the definition varies by country. In addition, the definition within countries has varied from time to time. Nevertheless, experts believe that the U.N. data more or less reflect the overall trend of urbanization.

FURTHER READING

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The Growing Urbanization of the World. Earth Institute at Columbia University. www.earth.columbia.edu/news/2005/story03-07-05.html

DATA POINTS: EGGING ON

This past spring Woo Suk Hwang of Seoul National University in South Korea and his colleagues reported stem cell work in which they inserted DNA from skin cells into donated eggs. Some of the fused eggs grew to form blastocysts, an early stage of development from which the researchers harvested stem cells. The small study also highlights in a novel way how the quality of eggs declines with age.

Number of egg donors:

Younger than age 30: 10

Older than age 30: 8

Percent of eggs fused with DNA that developed into blastocysts from donors:

Under 30: 24.4

Over 30: 23.1

Percent of blastocysts that yielded stem cells from donors:

Under 30: 40.9

Over 30: 22.2

Percent of stem cell lines established from oocytes from donors:

Under 30: 7.2

Over 30: 3.3

SOURCE: Science, *June 17*

EVOLUTION

Battle of the Sexes

Relationship gurus may quip that men and women are from different planets, but in one case at least, males and females may be different species. Researchers from France, Switzerland, Belgium and Japan investigating colonies of the little fire ant *Wasmannia auropunctata* in French Guiana and New Caledonia discovered that unlike other ants, queens of the species essentially clone themselves. They emerge from unfertilized eggs and receive genes solely from their mothers. Not to be outdone, male little fire ants also clone themselves, via a male genome that can apparently eliminate any female genetic contribution in fertilized eggs, thereby leading to sons being exact copies of fathers. Only the sterile workers of the species inherit genes from both parents, meaning that the male and female gene pools are independent branches in the ant family tree. The June 30 *Nature* has the details.

—Charles Q. Choi

WHO NEEDS SEX? Females and males of the little fire ant can clone themselves.

NEUROBIOLOGY

Back-Channel Chatter

Synapses, the specialized junctions between neurons through which chemical messages flow, may not be the only places where nerve cells communicate. Based on electron microscope images of a chick embryo synapse, Terrence J. Sejnowski of the Salk Institute for Biological Studies in La Jolla, Calif., and his colleagues developed a three-dimensional computer model detailed down to nine nanometers. The investigators simulated the release of messenger chemicals and neurotransmitters within the synapse and compared their data with recordings from living cells. The data from the real neurons and the model matched only when the model released a whopping 90 percent of the neurochemicals outside the synapse. These emissions seem to almost always only activate receptors similarly lying outside the synapse, suggesting hitherto unknown channels of communication that may be more important than synapse-to-synapse chatter. The findings appear in the July 15 *Science*.

—Charles Q. Choi

CONSERVATION

Working Corridors

Fluorescent bird droppings may help shed light on contested predictions in ecology. To keep species from becoming isolated in fragmented landscapes, conservation biologists often join the patches with strips of habitat, a strategy whose usefulness has been controversial. Ornithologists from the University of Florida at Gainesville and elsewhere devised a large-scale test of such corridors with eight sites in South Carolina pine forests. Each site contained a 100-meter-square patch with wax myrtle bushes, a key source of food for the eastern bluebird. This patch was surrounded by three isolated patches and connected to a fourth by a 150-meter-long corridor. After spraying the wax myrtle fruit with fluorescent powder and analyzing the resulting 11,000 fluorescent bluebird droppings, the researchers found the feces were 37 percent more likely to occur in the connected patch than in the isolated ones, suggesting corridors do work. Their report appears in the July 1 *Science*.

—Charles Q. Choi

WILDLIFE PATHS, such as this one in Banff National Park in Canada, prevent habitat isolation.

CHRISTIAN KÖNIG (*top*); ALAN SIRULNIKOFF *Science Photo Library* (*bottom*); ILLUSTRATION BY MATT COLLINS

BIOTECH

In Meatro

Talk about a meat dish. A team has proposed a way to grow meat in the lab. Muscle precursors called myoblasts and myosatellite cells could be extracted from a desired animal and grown on a grooved biofilm or on small collagen beads that swell when heated. Stretching the film or expanding the beads just 10 percent at a time should induce the cells to fuse and become muscle fibers. Investigators have already produced skeletal muscle for clinical applications, and team member Vladimir Mironov of the Medical University of South Carolina is currently growing chicken cells on beads. In theory, a handful of animals could produce the world's meat supply without being sacrificed, says Jason Matheny of the University of Maryland, co-author of the May issue *Tissue Engineering* paper that lays out these ideas. *—JR Minkel*

IS IT HONEY-GLAZED? Lab-grown meat is possible, theoretically.

PHYSICS

A Better Time Machine

Scientific proposals for time machines are always a letdown: *If* you had an infinitely long cylinder. *If* you could get a glob of stuff with negative energy density. *If* it could resist quantum-mechanical fluctuations. Physicist Amos Ori of the Israel Institute of Technology in Haifa hasn't exactly invented the flux capacitor used in *Back to the Future*, but his latest idea has a couple things going for it: finite size and no need for questionable negative energy to prop it open. He reasons that a doughnut-shaped vacuum containing a certain doughnut-shaped gravitational field in otherwise ordinary space constitutes a time machine. Fly your spaceship into the toroid and exit at any time of your choosing, as far back as the creation of the time machine. The remaining questions are whether it is stable and how to set one up—Ori does not know how but speculates that possibilities include focusing gravitational waves or whirling some really massive object around. Catch the July 7 *Physical Review Letters* for more. *—JR Minkel*

ASTRONOMY

The Comet's White Glare

On July 4, well before all the fireworks, NASA's Deep Impact probe slammed into Comet Tempel 1 at 10 kilometers per second. Designed to lay bare the comet's innards as a way of studying the composition of the early solar system, the collision caused a glow that revealed the comet's surface features, including possible impact craters. It also kicked up a fan-shaped plume of fine dust, gas and organic compounds moving at twice the speed of a commercial jet. Initial analysis of the ejecta suggests that the surface is highly porous and held together weakly by gravity, possibly indicating that the comet formed slowly. The mission team is still working to determine how much ice escaped the comet as gas. "We will have years of continuing analysis," says principal investigator Michael F. A'Hearn of the University of Maryland, "and we should have new results on a regular basis." *—JR Minkel*

SMASHING: Debris shoots out after a NASA probe collides with Comet Tempel 1, as seen by the Hubble Space Telescope.

PHOTOILLUSTRATION BY EMILY HARRISON, CORBIS (*petri dish*) AND ROGER CHESTER *Eye Ubiquitous/Corbis* (*meat*) (*top*); NASA, ESA, P. FELDMAN *Johns Hopkins University* AND H. WEAVER *Johns Hopkins Applied Physics Lab* (*bottom*)

BRIEF POINTS

- **Cosmic maser: In the first direct observation of the process, astronomers have discovered that the light from a pulsar stimulates the emission of microwave photons in a hydroxyl cloud.**

  Science, July 1

- **Drugs meant to starve tumors of blood have been disappointing, perhaps because stress from lack of blood stimulates the cancer cell to produce a survival protein called GRP78, which blocks cell death.**

  Cancer Research, July 1

- **Space shuttle blastoffs can seed the creation over Antarctica of polar mesospheric clouds, which form above the stratosphere. The formation provides clues about the global transport processes in the atmosphere.**

  Geophysical Research Letters, July 6

- **The region of the macaque's brain that controls jaw movements is a direct homologue of Broca's area, the brain part for speech in people. The finding contradicts the theory that speech evolved from novel neural structures specific to humans.**

  Nature, June 30

Rumsfeld's Wisdom

Where the known meets the unknown is where science begins By MICHAEL SHERMER

At a February 12, 2002, news briefing, Secretary of Defense Donald Rumsfeld explained the limitations of intelligence reports: "There are known knowns. There are things we know we know. We also know there are known unknowns. That is to say, we know there are some things we do not know. But there are also unknown unknowns, the ones we don't know we don't know."

Rumsfeld's logic may be tongue-twisting, but his epistemology was sound enough that he was quoted twice at the World Summit on Evolution. The June conference, hosted by San Francisco University of Quito, was held on the Galápagos island of San Cristóbal, where Charles Darwin began his explorations. Rumsfeld's wisdom was first invoked by University of California at Los Angeles paleobiologist William Schopf, who, in a commentary on a lecture on the origins of life, asked: "What do we know? What are the unsolved problems? What have we failed to consider?"

Disputation is at the heart of a robust science.

Creationists and outsiders often mistake the last two categories for signs that evolution is in trouble or that contentious debate between what we know and do not know means that the theory is false. Wrong. The summit revealed a scientific discipline rich in data and theory as well as controversy and disputation over the known and unknown.

For example, Schopf began with the known: "We know the overall sequence of life's origin, from CHONSP [carbon, hydrogen, oxygen, nitrogen, sulfur, phosphorus], to monomers, to polymers, to cells; we know that the origin of life was early, microbial and unicellular; and we know that an RNA world preceded today's DNA-protein world. We do not know the precise environments of the early earth in which these events occurred; we do not know the exact chemistry of some of the important chemical reactions that led to life; and we do not have any knowledge of life in a pre-RNA world." As for what we have failed to consider, Schopf noted a problem with what he called "the pull of the present"—it is extremely difficult to model the early earth's atmosphere and the biochemistry of early life because we are so accustomed to conditions today.

Rumsfeld's heuristic was summoned again at the end of the conference by University of Georgia evolutionary biologist Patricia Gowaty, in response to Stanford University biologist Joan Roughgarden, who declared that Darwin's theory of sexual selection is wrong in its claim that females choose mates who are the most attractive. "People are surprised to learn how much sex animals have for purely social reasons and how many species have sex-role reversal in which the males are drab and the females are colorfully ornamented and compete for the attention of males," Roughgarden said. Gowaty agreed that exceptions to Darwin's theory exist and that there are many unknowns. But, she added, since Darwin much has been learned about mate selection and competition.

Between these Rumsfeldian bookends, scientific skepticism was rampant. University of Massachusetts Amherst biologist Lynn Margulis said that "neo-Darwinism is dead," because "random changes in DNA alone do not lead to speciation. Symbiogenesis—the appearance of new behaviors, tissues, organs, organ systems, physiologies or species as a result of symbiont interaction—is the major source of evolutionary novelty in eukaryotes: animals, plants and fungi." University of California at Berkeley paleoanthropologist Timothy White suggested that his colleagues have engaged in far too much species splitting in classifying fossil hominids. American Museum of Natural History paleontologist Niles Eldredge explained how punctuated equilibrium—the idea that long periods of species stability are punctuated by rapid bursts of speciation—better accounts for the fossil record than the theory of slow and steady gradualism.

During the conference, I had a nightmarish thought: creationists could have a field day yanking quotes out of context while listening to a room full of evolutionary biologists arguing over specific issues. In point of fact, such debates are all *within* evolutionary theory, not between evolutionary theory and something else. And this boundary between the known and the unknown is where science flourishes. SA

Michael Shermer is the publisher of Skeptic *(www.skeptic.com). His latest book is* Science Friction.

BRAD HINES

A Proposition for Stem Cells

Last fall Robert Klein got Californians to vote for embryonic stem cell work. That was a piece of cake compared with getting the resulting research agency off the ground By SALLY LEHRMAN

When the oversight board for California's stem cell research agency met in late May, South Korean scientists had just described a breakthrough in so-called therapeutic cloning. David A. Kessler, dean of the University of California at San Francisco School of Medicine, pressed fellow board members for clarification. "So we're not cloning human beings?" he asked. "No, we're taking the cells out at a very, very early level of development and cloning *cells,*" answered neuroscientist Zach W. Hall, the state agency's interim president.

With stem cell research under a microscope, the California Institute for Regenerative Medicine (CIRM) takes great pains to make its intentions clear. The institute, dreamed up by real estate investment banker Robert Klein and approved as Proposition 71 by voters last November, funds embryonic stem cell research that the federal government will not.

TIMOTHY ARCHIBALD

ROBERT KLEIN: TAKING THE INITIATIVE

- Completed 30 drafts and 200 subsection revisions to make Proposition 71 watertight against financial obstacles and legislative meddling.
- On the future of state-sponsored stem cell work: "If California's institute doesn't work, other institutes will be crippled."

Klein wrote the bulk of the California Stem Cell Research and Cures Initiative, donated $2.6 million of his own money and served as its biggest promoter. Last December the state's top elected officers named him chair, responsible for setting up the agency and overseeing a $3-billion pot of research money.

Although 59 percent of California voters approved the idea, actually creating the agency has proved contentious. Months after Klein had intended to announce CIRM's first grants, he finds himself struggling to develop an infrastructure and battling legal and legislative challenges. One powerful early supporter, State Senator Deborah Ortiz, has demanded stricter conflict-of-interest rules and policies to ensure that royalties, revenues and therapies benefit state residents. Advocates of open government and biotech skeptics have contested provisions that were originally intended to shield decision making from the bureaucracy of state government and allow the agency to operate like an entrepreneurial start-up.

Klein refers in frustration to the 29 public meetings he has overseen in 22 weeks—and still, he complains, CIRM faces criticism that it does not operate openly enough. "There's some legitimate anxiety about achieving high standards, and we've had to prove ourselves," Klein says. But he insists, "We've delivered on what we said we would."

The 59-year-old Klein is no stranger to the public process. As a real estate developer and banker, he helped to establish a state agency that provides below-market-rate housing loans and has structured bond financing for private and government bodies. His passion for stem cells took root five years ago at a fundraiser for the Juvenile Diabetes Research Foundation

International. Jeffrey Bluestone of U.C.S.F. spoke about islet cell transplantation from donated organs, and Klein was struck by the potential. The downstream delivery system was in place, he realized—what was missing were the embryonic stem cells that might restore insulin production without triggering an immune response. He contributed generously that night, a year before his own son would be diagnosed with the disease.

Soon the foundation recruited Klein to lobby for renewed funding of the National Institutes of Health's juvenile diabetes program, which was slated to end in 2002. He helped to win $300 million for both adult and juvenile forms. But he decided that legislation was a poor way to support research, a view strengthened in 2003 when a bill sponsored by Ortiz to fund embryonic stem cell studies in California foundered.

To Klein, medical research should be viewed as a part of the public infrastructure, like a dam or a bridge. "You've got to stop 'expensing' research," he says. "You've got to put it in the state constitution and authorize state bonds for it as a capital asset." The approach protects controversial areas of study and allows the state to account for costs over decades instead of every year. With this philosophy, Klein proposed a way for citizens to demand long-term funding. For nine months he worked with scientists, patient advocates and a team of prominent lawyers, and they eventually crafted Proposition 71 for the 2004 ballot.

VICTORY IN NOVEMBER: Klein and supporters celebrate after voters passed Proposition 71.

CHRIS CARLSON AP Photo

Besides challenging traditional methods of funding, Klein says, CIRM can also streamline work for scientists by reducing legal and administrative burdens and accelerating the grant review process. He might negotiate a statewide master license on intellectual property, for instance, so that biological material could move between institutions. He would like to approve grants on a three-month timeline instead of the nine months required by the NIH. "I believe we have a mandate from the public to improve the current model," Klein declares. Besides paying for work unlikely to win federal money, CIRM could be more adventuresome than the NIH, Hall adds. As a model, Hall points to the sequencing race in which the private firm Celera challenged the NIH's Human Genome Project.

Scientists outside California hope CIRM will succeed, but they are not as certain that improvements are needed and fear that the "can-do" attitude of entrepreneurialism may not work well for research. Applying a lot of money to a biological problem does not ensure results, cautions Stuart H. Orkin of Children's Hospital Boston. Orkin, who will chair CIRM's grants working group, also notes that federal standards for quality, peer review, conflict of interest, and ethics have been honed over many years at the NIH. Like others, he worries that a patchwork of guidelines is developing as more states pursue this work. New Jersey has dedicated $11.5 million for its own stem cell institute, with another $380 million in the works. Nine other states are considering their own funding efforts or regulatory schemes. And private donations have enabled several institutions to set up research centers independently.

The proliferation may relieve pressure on the Bush administration to loosen its stance on stem cells. But the separate rules for private, state and federal funding confuse both scientists and the public, says Gordon M. Keller, director of the stem cell institute at the Mount Sinai School of Medicine. Whereas many states are happy to finance embryonic stem cells, six states have banned cloning research. "How can it be moral to do research with one [type of funds] but not the other?" he asks.

CIRM's scientific and medical accountability board did adopt proposed national oversight and ethical guidelines laid out by the National Academy of Sciences, but the rules still must go through a 270-day public review. While California stem cell biologists impatiently await standards for consent, oocyte tracking and other processes, some scientists working elsewhere in the nation would like to see a more cautious, deliberate approach. Keller worries about the public's moral qualms as well as what he sees as unrealistically high expectations from stem cell enthusiasts for therapies, new jobs and health care savings.

Others think that the public, particularly patient advocates, may have too much power at CIRM. They make up at least one quarter of the grants review board and a third of the oversight committee. Mildred K. Cho, associate director of the Stanford Center for Biomedical Ethics, wonders about the long-term effect on the culture of science when research is funded by popular vote. She points to the patient-driven factions arising around autism research, in which parent groups attack study results they don't like and raise money to test their own treatment theories. "The public drives not just what disease areas get attention but what the research strategies are," she warns.

Klein believes he has an institute that will be able to lead the way responsibly. "There's a tremendous amount of experience and knowledge on our board," he says. Klein clearly feels all eyes are on him as the institute navigates the scientific, financial, political and ethical shoals of embryonic stem cell research. If California can achieve a major breakthrough, he predicts, "the nation will change forever in this area of science." SA

Sally Lehrman is based in Montara, Calif.

THE CLIMAX OF HUMANITY

BY GEORGE MUSSER

Demographically and economically, our era is unique in human history. Depending on how we manage the next few decades, we could usher in environmental sustainability—or collapse

The 21st century feels like a letdown. We were promised flying cars, space colonies and 15-hour workweeks. Robots were supposed to do our chores, except when they were organizing rebellions; children were supposed to learn about disease from history books; portable fusion reactors were supposed to be on sale at the Home Depot. Even dystopian visions of the future predicted leaps of technology and social organization that leave our era in the dust.

Looking beyond the blinking lights and whirring gizmos, though, the new century is shaping up as one of the most amazing periods in human history. Three great transitions set in motion by the Industrial Revolution are reaching their culmination. After several centuries of faster-than-exponential growth, the world's population is stabilizing. Judging from current trends, it will plateau at around nine billion people toward the middle of this century. Meanwhile extreme poverty is receding both as a percentage of population and in absolute numbers. If China and India continue to follow in the economic footsteps of Japan and South Korea, by 2050 the average Chinese will be as rich as the average Swiss is today; the average Indian, as rich as today's Israeli. As humanity grows in size and wealth, however, it increasingly presses against the limits of the planet. Already we pump out carbon dioxide three times as fast as the oceans and land can absorb it; midcentury is when climatologists think global warming will really begin to bite. At the rate things are going, the world's forests and fisheries will be exhausted even sooner.

These three concurrent, intertwined transitions—demographic, economic, environmental—are what historians of the future will remember when they look back on our age. They are transforming everything from geopolitics to the structure of families. And they pose problems on a scale that humans have little experience with. As Harvard University biologist E. O. Wilson puts it, we are about to pass through "the bottleneck," a period of maximum stress on natural resources and human ingenuity.

The trends are evident in everyday life. Many of us have had the experience of getting lost in our hometowns because they have grown so much. But growth is slowing as families shrink. Ever more children grow up not just without siblings but also without aunts, uncles or cousins. (Some people find that sad, but the only other way to have a stable population is for death rates to rise.) Chinese goods line Wal-Mart shelves, Indians handle customer-service calls, and, in turn, ever more Asians buy Western products. Spring flowers bloom a week earlier than they did 50 years ago because of global warming, and restau-

THREE GREAT HISTORICAL TRENDS define the present day. Understanding them provides a framework for dealing with, rather than becoming paralyzed by, the problems of the world.

MAX ROSSI *Reuters/Corbis (crowd with banners)*; JOERG KOCH *AFP/Getty Images (skyscrapers)*; SCOTT NELSON *Getty Images (smokestacks)*; STEPHEN FERRY *Liaison/Getty Images (logger)*; JEFF ZELEVANSKY *Reuters/Corbis (shoppers)*; CHRISTIAN SIMONPIETRI *Corbis Sygma (group of men)*

HUMANITY HAS GROWN,

GOTTEN RICHER

AND TRANSFORMED THE PLANET

rants serve different types of fish than they used to because species that were once common have been fished out.

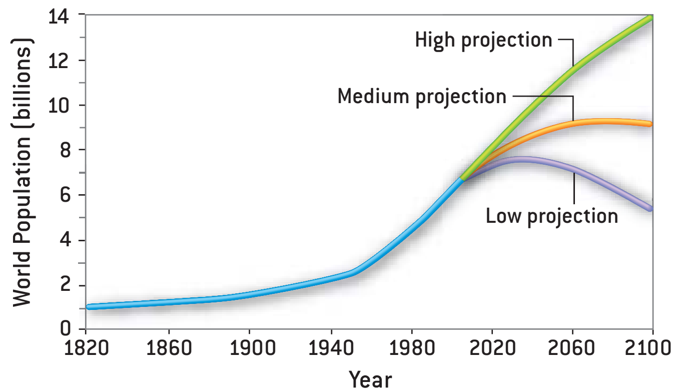
Looking at the present era in historical context helps to put the world's myriad problems in perspective. Many of those problems stem, directly or indirectly, from growth. As growth tapers off, humanity will have a chance to close the books on them. A bottleneck may be tough to squeeze through, but once you do, the worst is behind you.

The transitions we are undergoing define the scope of the challenges. Scientists can estimate, at least roughly, how many people will inhabit Earth, what they are going to need and want, what resources are available, and when it is all going to happen. By the latter half of this century, humanity could enter an equilibrium in which economic growth, currently driven by the combination of more productivity, more people and more resources, will flow entirely from productivity—which would take much of the edge off conflicts between the economy and the environment. Old challenges will give way to new ones. This process is already evident in countries at the leading edge of the transitions. The Social Security debate in the U.S., like worries about pensions in Europe and Japan, is the sound of a society planning for life after growth.

In the public's eyes, demographers have a checkered reputation. Thirty years ago, wasn't overpopulation the big concern? Paul Ehrlich's book *The Population Bomb* was a best seller. The film *Soylent Green*, starring Charlton Heston, dramatized a future in which people would be stacked like cordwood and fed little squares that looked like tofu but weren't. Lately, though, underpopulation has become the cause célèbre, her-

THREE WORLD-CHANGING TRANSITIONS

POPULATION GROWTH IS SLOWING . . .



ACTION PLAN FOR THE 21ST CENTURY

1. Understand the changes (page 48). Obvious though it may seem, this first step is so often neglected. It can be hard to look past the daily headlines to understand the core trends we are experiencing. Demographer Joel E. Cohen paints the broad picture of a larger, slower-growing, more urbanized and older population. The detailed projections are uncertain, but what is important is the general issues that they raise.

2. Achieve Millennium Development Goals (page 56). This month the United Nations General Assembly is reviewing the mixed progress toward these quantitative goals for reducing poverty and inequality. Economist Jeffrey D. Sachs, head of the U.N. Millennium Project, argues for a concerted aid effort. Besides advancing human well-being, it would ease environmental problems that are linked with poverty, such as air pollution and deforestation.

3. Preserve crucial habitats (page 66). Extinction is irreversible, so avoiding it is a top priority. Obscure creatures are not the only victims; economically valuable species, such as sturgeon and wild grain varieties, are also in trouble. Ecologists Stuart L. Pimm and Clinton Jenkins argue that rounding out nature reserves will cost money but bring multiple benefits. Even in narrow economic terms, countries are often better off saving old-growth forest than converting it to farms or ranches.

4. Wean off fossil fuels (page 74). The atmosphere can hold only so much carbon dioxide before the climate goes haywire. Reducing emissions requires extensive changes to how we produce and use energy, but Amory B. Lovins, one of the country's most innovative thinkers on the subject, argues that the task is not nearly as daunting or costly as you might think. Accelerating the existing trend toward higher efficiency could do the trick.

5. Provide cheap irrigation to poor farmers (page 84). How can we feed all those new mouths without trashing the soil, exhausting aquifers and damming every last river? Development specialist Paul Polak argues that small-scale appropriate technology, such as manual pumps and drip irrigation, can boost yields, stretch out limited water supplies and start farmers on the path to prosperity.

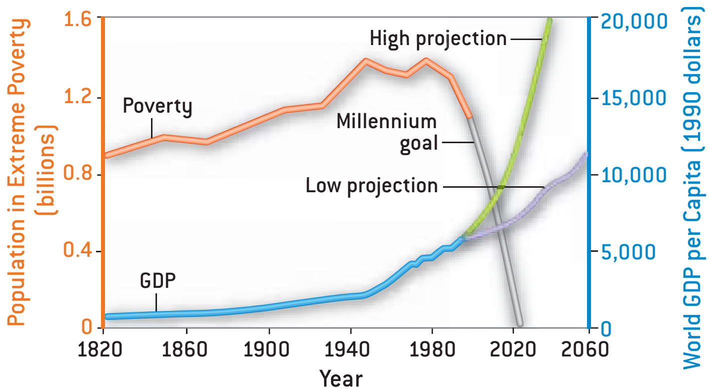
6. Beef up health systems (page 92). In rich countries and rapidly developing ones such as China and India, more people now get sick from chronic conditions, such as heart disease and mental illness, than from infections. In poorer countries, malaria, tuberculosis and other bugs remain the big burden. Epidemiologist Barry R. Bloom argues that in both cases, the top priority is better prevention, ranging from vaccines and mosquito nets to antismoking campaigns.

7. Brace for slower growth (page 100). Political and financial institutions will have to retool as the economy approaches global constraints. Economist Herman E. Daly argues for new ways to collect taxes, set interest rates, and regulate pollution and resource extraction. In an accompanying commentary, economist Partha Dasgupta agrees with much of what Daly says but suggests that rich-country economies are already more sustainable than many people assume.

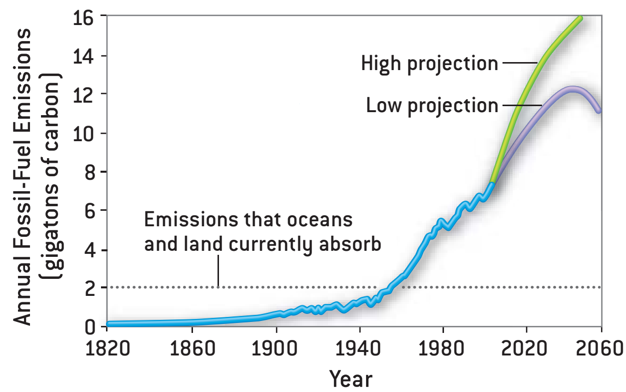
8. Prioritize more rationally (page 108). Right now priorities are set largely by who shouts the loudest or plays golf with the right people. As staff writer W. Wayt Gibbs describes, economists and environmental scientists have been working on better approaches. With costs and benefits properly priced in, markets can act as giant distributed computers that weigh trade-offs. But they can fail, for example, when costs are concentrated and benefits are diffuse.

JEN CHRISTIANSEN; SOURCES: ANGUS MADDISON *University of Groningen* (*historical population* and *GDP*); U.N. POPULATION DIVISION (*population projections*); INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE (*economic projections, scenarios A1 AIM and A2 ASF, rescaled; emissions projections, scenarios A2 ASF and B1 IMAGE*); FRANÇOIS BOURGUIGNON *École des Hautes Études en Sciences Sociales* AND CHRISTIAN MORRISSON *University of Paris-I* (*historical poverty*); WORLD BANK 2005 WORLD DEVELOPMENT INDICATORS (*2001 poverty*); U.N. MILLENNIUM PROJECT (*poverty projection*); G. MARLAND, T. A. BODEN AND R. J. ANDRES *Oak Ridge National Laboratory* (*historical emissions*); DREW SHINDELL *NASA Goddard Institute for Space Studies* (*sustainable emissions level*)

... PROSPERITY IS SPREADING ...



... BUT CO_2 EMISSIONS ARE TROUBLING



alded by neoconservatives such as Nicholas Eberstadt. Their concern is epitomized by another Heston movie: *The Omega Man,* in which humanity dwindles to nothingness. So which will it be: Too many people or too few?

Mainstream demographers have not swung back and forth nearly as much as these extreme depictions might suggest. Families in the developing world have shrunk faster than expected, but the forecasts described in *Scientific American*'s 1974 special issue on population have largely stood the test of time. In fact, the *Soylent Green* and *Omega Man* scenarios each contain an element of truth. Humanity is still growing enormously in absolute terms, and past success at avoiding Malthusian nightmares is no guarantee of future performance. The decline in growth rates is a worry, though. Historically, most stable or shrinking societies have been down at heel.

Partisans of one scenario shrug off the challenges of the other, expressing "confidence" that they can be handled without actually doing much to ensure that they are. Once you blow away the fog of ideology, the outlines of a comprehensive action plan begin to emerge [*see box on opposite page*]. It is hardly the only way forward, but it can serve as a starting point for discussion.

A recurring theme of this plan is that business is not necessarily the enemy of nature, or vice versa. Traditionally the economy and environment have not even been described in like terms. The most-watched economic statistics, such as gross domestic product (GDP), do not measure resource depletion; they are essentially measures of cash flow rather than balance sheets of assets and liabilities. If you clear-cut a forest, GDP jumps even though you have wiped out an asset that could have brought in a steady stream of income.

More broadly, the prices we pay for goods and services seldom include the associated environmental costs. Someone else picks up the tab—and that someone is usually us, in another guise. By one estimate, the average American taxpayer forks out $2,000 a year to subsidize farming, driving, mining and other activities with a heavy environmental footprint. The distorted market gives consumers and producers little incentive to clean up. Environmentalists inadvertently reinforce this tendency when they focus on the priceless attractions of nature, which are deeply meaningful but difficult to weigh against more pressing concerns. The Endangered Species Act has provided iconic examples of advocates talking past one another. Greens blamed the plight of spotted owls on loggers; the loggers blamed unemployment on self-indulgent ornithology. In fact, both were victims of unsustainable forestry.

In recent years, economists and environmental scientists have come together to hang a price tag on nature's benefits. Far from demeaning nature, this exercise reveals how much we depend on it. The *Millennium Ecosystem Assessment,* published earlier this year, identified services—from pollination to water filtration—that humans would have to provide for themselves, at great cost, if nature did not. Of the 24 broad categories of services, the team found that 15 are being used faster than they regenerate.

When the environment is properly accounted for, what is good for nature is often what is good for the economy and even for individual business sectors. Fishers, for example, maximize their profits when they harvest fisheries at a sustainable level; beyond that point, both yields and profits decline as more people chase ever fewer fish. To be sure, life is not always so convenient. Society must sometimes make real trade-offs. But it is only beginning to explore the win-win options.

If decision makers can get the framework right, the future of humanity will be secured by thousands of mundane decisions: how many babies people have, where they graze their cattle, how they insulate their houses. It is usually in mundane matters that the most profound advances are made. What makes a community rich is not the computers and the DVDs, which you can find nowadays even in humble villages. It is the sewage pipes, the soft beds, the sense of physical and economic security. By helping to bring these benefits of modernity to all, science and technology will have done something more spectacular than building space colonies. SA

George Musser is a staff writer and editor.

HUMAN POPULATION GROWS UP

BY JOEL E. COHEN

As we swell toward nine billion in the next half a century, humanity will undergo historic changes in the balance between young and old, rich and poor, urban and rural. Our choices now and in the years ahead will determine how well we cope with our coming of age

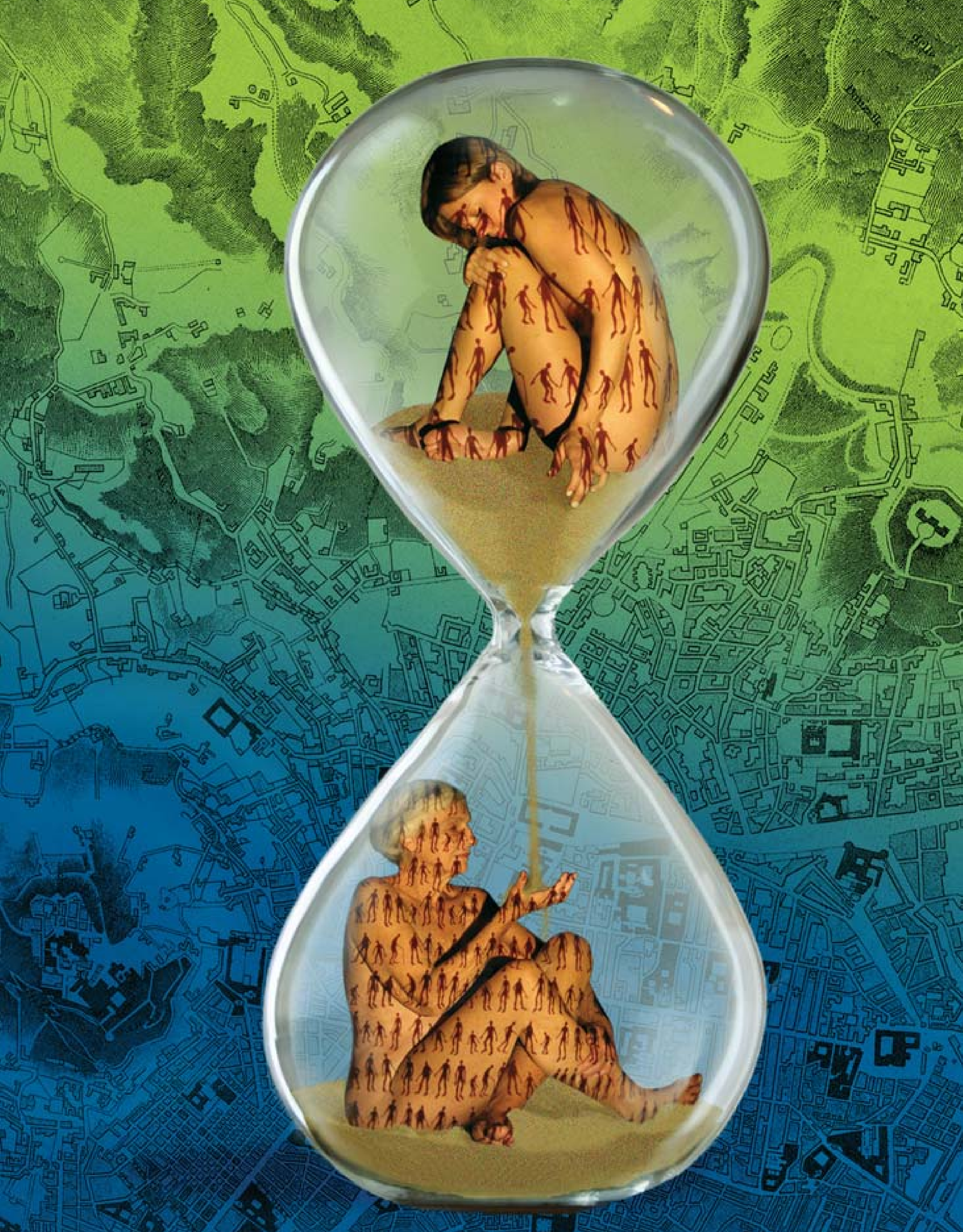
THE YEAR 2005 is the midpoint of a decade that spans three unique, important transitions in the history of humankind. Before 2000, young people always outnumbered old people. From 2000 forward, old people will outnumber young people. Until approximately 2007, rural people will have always outnumbered urban people. From approximately 2007 forward, urban people will outnumber rural people. From 2003 on, the median woman worldwide had, and will continue to have, too few or just enough children during her lifetime to replace herself and the father in the following generation.

The century with 2000 as its midpoint marks three additional unique, important transitions in human history. First, no person who died before 1930 had lived through a doubling of the human population. Nor is any person born in 2050 or later likely to live through a doubling of the human population. In contrast, everyone 45 years old or older today has seen more than a doubling of human numbers from three billion in 1960 to 6.5 billion in 2005. The peak population growth rate ever reached, about 2.1 percent a year, occurred between 1965 and 1970. Human population never grew with such speed before the 20th century and is never again likely to grow with such speed. Our descendants will look back on the late 1960s peak as the most significant demographic event in the history of the human population even though those of us who lived through it did not recognize it at the time.

Second, the dramatic fall since 1970 of the global population growth rate to 1.1 or 1.2 percent a year today resulted primarily from choices by billions of couples around the world to limit the number of children born. Global human population growth rates have probably risen and fallen numerous times in the past. The great plagues and wars of the 14th century, for example, reduced not only the growth rate but also the absolute size of global popula-

HUMANITY IN TRANSITION to a new stage of life will have to face new challenges.

JUDITH S. LARSEN



tion, both largely involuntary changes. Never before the 20th century has a fall in the global population growth rate been voluntary.

Finally, the last half a century saw, and the next half a century will see, an enormous shift in the demographic balance between the more developed regions of the world and the less developed ones. Whereas in 1950 the less developed regions had roughly twice the population of the more developed ones, by 2050 the ratio will exceed six to one.

These colossal changes in the composition and dynamics of the human population by and large escape public notice. Occasionally, one or another symptom of these profound shifts does attract political attention. Proposed Social Security reforms in the U.S., however, often fail to recognize the fundamental population aging, while debates in Europe and the U.S. over immigration policy often overlook the differences in population growth rates between these regions and their southern neighbors.

In this article, I will focus on the four major underlying trends expected to dominate changes in the human population in the coming half-century and some of their long-term implications. The population will be bigger, slower-growing, more urban, and older than in the 20th century. Of course, precise projections remain highly uncertain. Small changes in assumed fertility rates have enormous effects on the projected total numbers of people, for example. Despite such caveats, the projections do suggest some of the problems that humanity will have to face over the next 50 years.

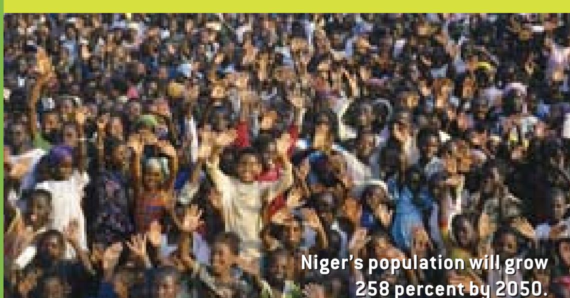
CROSSROADS FOR
POPULATION

THE PROBLEM:

- Rapid population growth will boost human numbers by nearly 50 percent, from 6.5 billion now to 9.1 billion in 2050. Virtually all this growth will happen in existing or new cities in developing countries. During the same period, many richer nations will lose population. Falling fertility and increasing longevity worldwide will expand the proportion of potentially dependent elderly people.

THE PLAN:

- Create a bigger pie, and fewer forks, and better manners: Intensify human productive capacity through investment in education, health and technology. Increase access to reproductive health care and contraception to voluntarily slow population growth. Improve the terms of people's interactions by reforming economic, political, civil and social institutions, policies and practices and achieving greater social and legal equity.



Niger's population will grow 258 percent by 2050.

FRANS LEMMENS *zefa/Corbis*

Rapid but Slowing Growth

ALTHOUGH THE RATE of population growth has fallen since the 1970s, the logic of compounding means that current levels of global population growth are still greater than any experienced prior to World War II. Whereas the first absolute increase in population by one billion people took from the beginning of time until the early 19th century, one billion people will be added to today's population in only 13 to 14 years. By 2050 the world's population is projected to reach 9.1 billion, plus or minus two billion people, depending on future birth and death rates. This anticipated increase of 2.6 billion people by 2050 over the 6.5 billion people of 2005 exceeds the total population of the world in 1950, which was 2.5 billion.

In short, rapid population growth has not ended. Human numbers currently increase by 74 million to 76 million people annually, the equivalent of adding another U.S. to the world every four years. But most of the increases are not occurring in countries with the wealth of the U.S. Between 2005 and 2050 population will at least triple in Afghanistan, Burkina Faso, Burundi, Chad, Congo, Democratic Republic of the Congo, East Timor, Guinea-Bissau, Liberia, Mali, Niger and Uganda. These countries are among the poorest on Earth.

Virtually all population growth in the next 45 years is expected to happen in today's economically less developed regions. Despite higher death rates at every age, poor countries' populations grow faster than rich countries' populations because birth rates in poor countries are much higher. At present, the average woman bears nearly twice as many children (2.9) in the poor countries as in the rich countries (1.6 children per woman).

Half the global increase will be accounted for by just nine nations. Listed in order of their anticipated contribution, they are India, Pakistan, Nigeria, Democratic Republic of the Congo, Bangladesh, Uganda, the U.S., Ethiopia and China. The only rich country on the list is the U.S., where roughly one third of population growth is driven by a high rate of immigration [*see box on page 54*].

In contrast, 51 countries or areas, most of them economically more developed, will lose population between now and 2050. Germany is expected to drop from 83 million to 79 million people, Italy from 58 million to 51 million, Japan from 128 million to 112 million and, most dramatically, the Russian Federation from 143 million to 112 million. Thereafter Russia will be slightly smaller in population than Japan.

Slowing population growth everywhere means that the 20th century was probably the last in human history in which younger people outnumbered older ones. The proportion of all people who were children aged four years and younger

POPULATION

Global population projections depend on assumptions about human choices.

The medium projection of **9.1 billion** people in 2050 assumes fertility will continue its downward trend

If women had, on average, just one-half child more than assumed, 2050 population would be **10.6 billion**

With one-half child less per woman, it would be **7.7 billion**

If 2005 fertility rates remained constant to 2050, population would reach **11.7 billion**

ER PRODUCTIONS *Corbis*

peaked in 1955 at 14.5 percent and gradually declined to 9.5 percent by 2005, whereas the fraction of people aged 60 years and older increased from a low of 8.1 percent in 1960 to 10.4 percent in 2005. Around 2000 each group constituted about 10 percent of humanity. Now and henceforth the elderly have the numerical upper hand.

This crossover in the proportions of young and old reflects both improved survival and reduced fertility. The average life span grew from perhaps 30 years at the beginning of the 20th century to more than 65 years at the beginning of the 21st century. The more powerful influence, however, is reduced fertility, adding smaller numbers to the younger age groups.

The graying of the population is not proceeding uniformly around the globe. In 2050 nearly one person in three will be 60 years or older in the more developed regions and one person in five in the less developed zones. But in 11 of the least developed countries—Afghanistan, Angola, Burundi, Chad, Democratic Republic of the Congo, Equatorial Guinea, Guinea-Bissau, Liberia, Mali, Niger and Uganda—half the population will be aged 23 years or younger.

If recent trends continue as projected to 2050, virtually all of the world's population growth will be in urban areas. In effect, the poor countries will have to build the equivalent of a city of more than one million people each week for the next 45 years.

Although long-term demographic projections to 2050 and beyond are routine, economic models are not well developed for long-term projection. They are vulnerable to unpredictable changes in institutions and technology and to shifts in the dominance of regions and economic sectors. Most models do, however, predict that the world will become richer. In the brightest scenarios, the ratio of per capita income in industrial nations to that in developing nations could drop from an estimated 16 to 1 in 1990 to between 6.6 to 1 and 2.8 to 1 in 2050. These gains are not assured. Other models predict stagnating poverty.

Projections of billions more people in developing countries and more elderly people everywhere, coupled with hopes of economic growth especially for the world's poor, raise concerns in some quarters about the sustainability of present and future populations.

Beyond Human Carrying Capacity

IN THE SHORT TERM, our planet can provide room and food, at least at a subsistence level, for 50 percent more people than are alive now because humans are already growing enough cereal grains to feed 10 billion people a vegetarian diet. But as demographer-sociologist Kingsley Davis observed in 1991, "There is no country in the world in which people

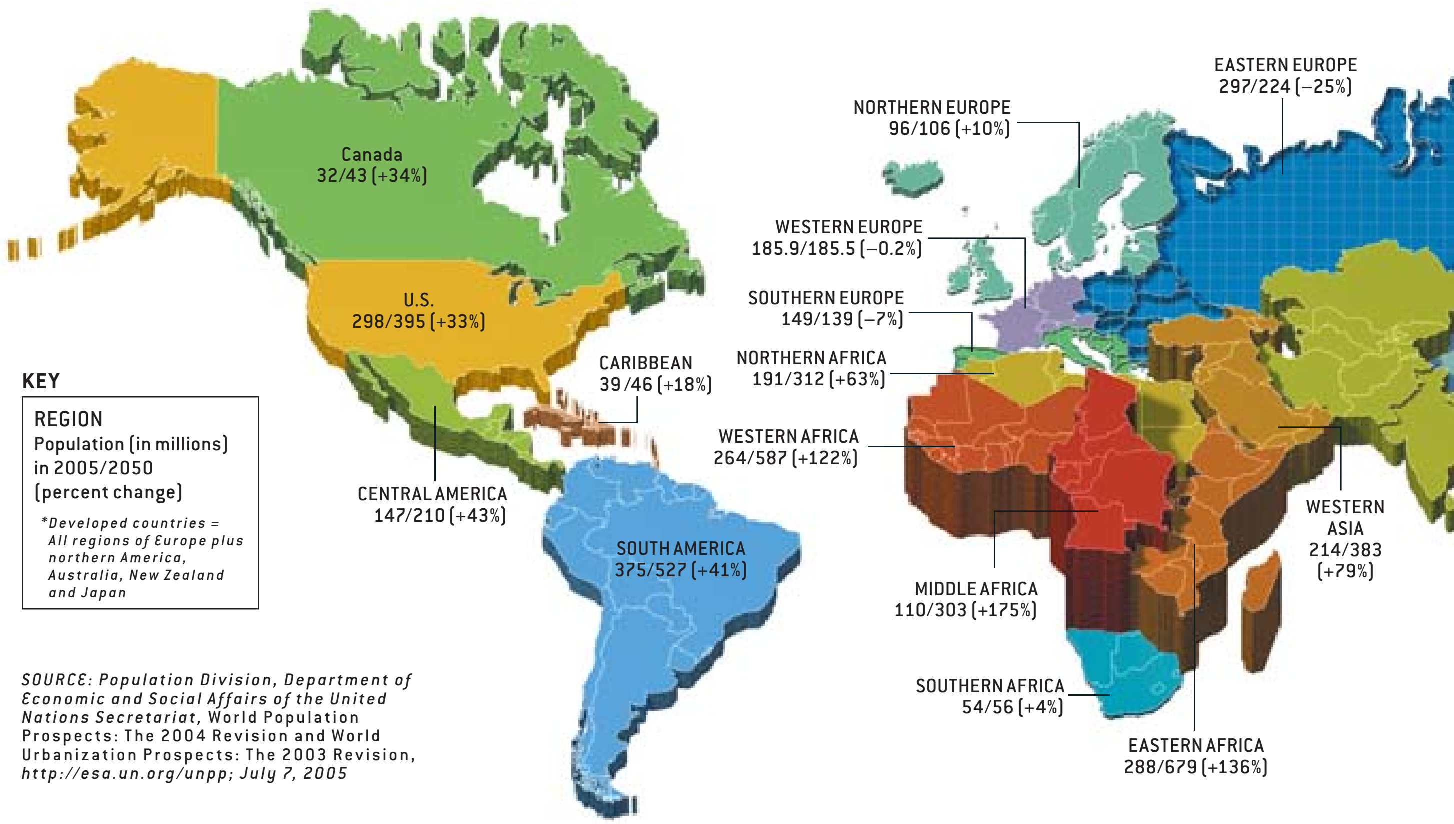
THE AUTHOR

JOEL E. COHEN

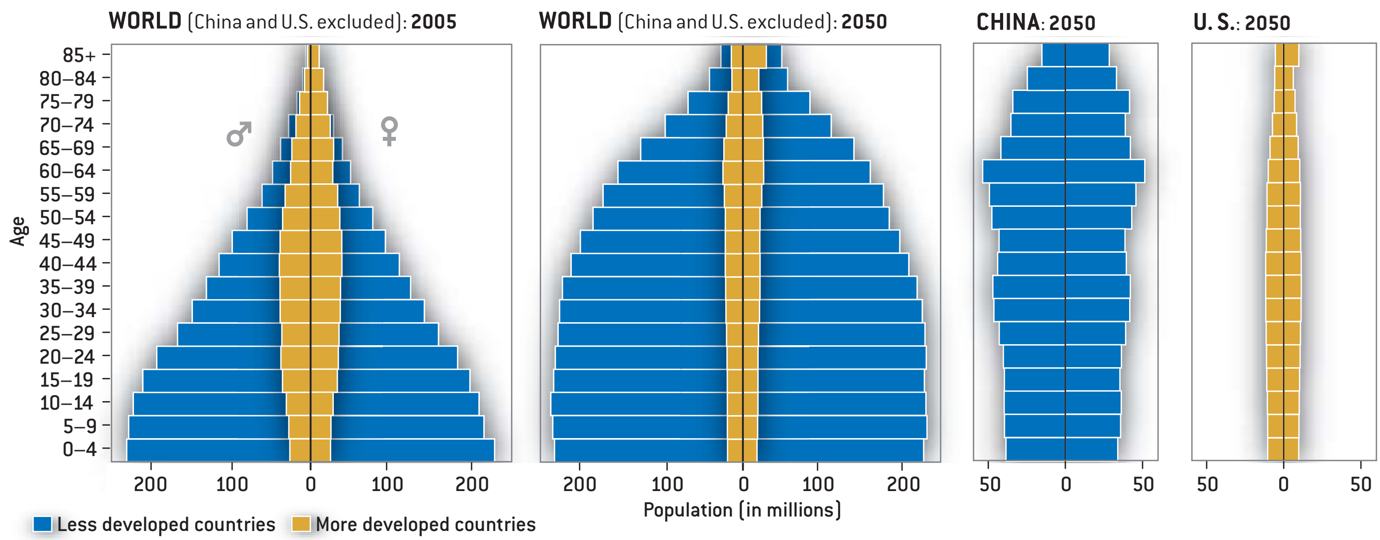
COHEN is Professor of Populations and head of the Laboratory of Populations at the Rockefeller University and Columbia University. He studies the population biology, demography, ecology and epidemiology of human and nonhuman populations using mathematics, statistics and computation. Author, co-author or editor of a dozen books and author of more than 320 papers, he has won the Tyler Prize for Environmental Achievement, the Nordberg Prize for excellence in writing in the population sciences, and the Fred L. Soper Prize of the Pan American Health Organization for his work on Chagas' disease. He enjoys playing the piano and being father to "the two best children in the world."

GLOBAL POPULATION IN TRANSITION

Uneven growth will further shift the population balance between rich and poor nations. In 2005 developed* countries are home to 1.2 billion of the world's 6.5 billion people; less developed countries are home to the other 5.3 billion. In 2050 the rich countries will still have about 1.2 billion people, but the poor countries will grow to 7.9 billion. Falling fertility rates will cause some rich nations to begin losing population from 2010 onward. Fertility will

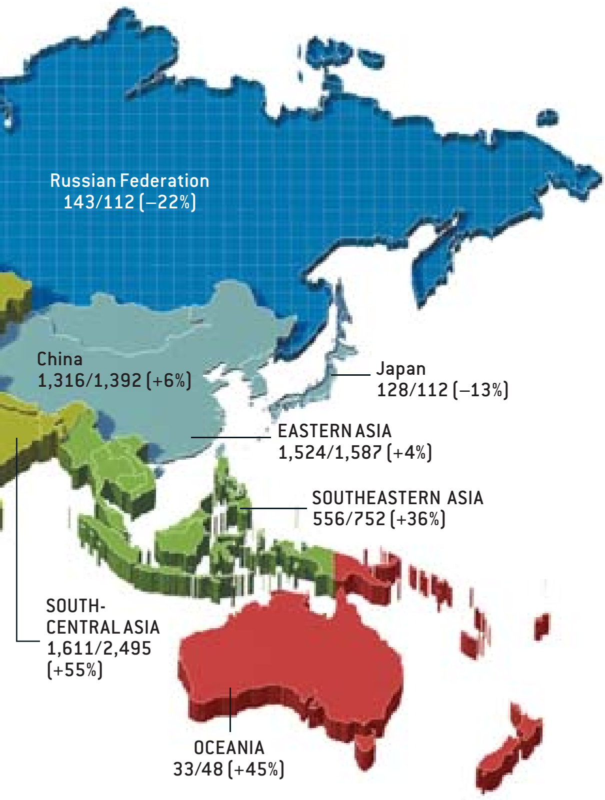


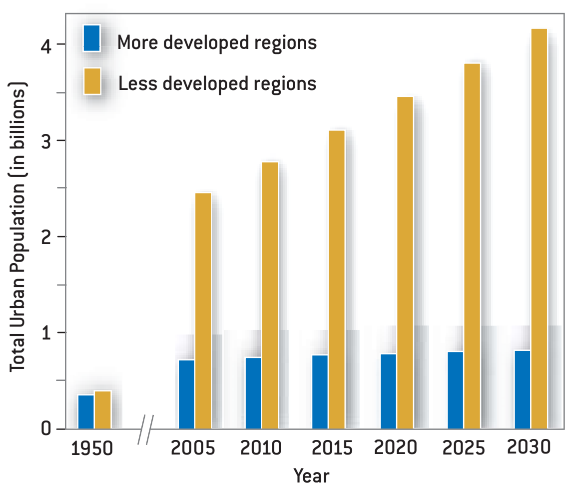
SOURCE: Population Division, Department of Economic and Social Affairs of the United Nations Secretariat, World Population Prospects: The 2004 Revision and World Urbanization Prospects: The 2003 Revision, *http://esa.un.org/unpp; July 7, 2005*



AGE STRUCTURE of populations is also shaped by fertility differences. In less developed countries, where population is growing rapidly, each new birth cohort is larger than its predecessor and the population resembles a broadly based pyramid. In more developed countries, where fertility is low and survival at old ages is high, the pyramid looks like a column that will become more top-heavy in the next 45 years. China and the U.S. are exceptions in their categories: China's long-standing one-child policy gives it a population structure more like that of the developed countries, and substantial immigration keeps the U.S. "younger" than most developed countries.

SOURCE FOR URBAN POPULATION GRAPH: *CITIES TRANSFORMED: DEMOGRAPHIC CHANGE AND ITS IMPLICATIONS IN THE DEVELOPING WORLD*, BY M. R. MONTGOMERY ET AL. NATIONAL ACADEMIES PRESS, 2003 also drop, on average, in developing countries, to a replacement level of 2.1 children per woman by around 2035, although birth rates in some of the poorest countries will remain higher.





URBAN POPULATIONS grow much faster in poor countries than in rich ones, according to projections displayed by national income level. About 60 percent of the developing countries' urban growth will result from the excess of births over deaths and the rest from migration of rural people to urban areas.

are satisfied with having barely enough to eat." The question is whether 2050's billions of people can live with freedom of choice and material prosperity, however freedom and prosperity may be defined by those alive in 2050, and whether their children and their children's offspring will be able to continue to live with freedom and prosperity, however they may define them in the future. That is the question of sustainability.

This worry is as old as recorded history. Cuneiform tablets from 1600 B.C. showed that the Babylonians feared the world was already too full of people. In 1798 Thomas Malthus renewed these concerns, as did Donella Meadows in her 1972 book *The Limits to Growth*. While some people have fretted about too many people, optimists have offered reassurance that deities or technology will provide for humankind's well-being.

Early efforts to calculate Earth's human carrying capacity assumed that a necessary condition for a sustainable human society could be measured in units of land. In the first known quantitative reckoning, Antoni van Leeuwenhoek estimated in 1679 that the inhabited area of Earth was 13,385 times larger than Holland and that Holland's population then was about one million people. Assuming that "the inhabited part of the earth is as densely populated as Holland, though it cannot well be so inhabited," he wrote, "the inhabited earth being 13,385 times larger than Holland yields … 13,385,000,000 human beings on the earth," or an upper limit of roughly 13.4 billion.

Continuing this tradition, in 2002 Mathis Wackernagel, an author of the "ecological footprint" concept, and his colleagues sought to quantify the amount of land humans used to supply resources and to absorb wastes. Their preliminary assessment concluded that humanity used 70 percent of the global biosphere's capacity in 1961 and 120 percent in 1999. In other words, by 1999 people were exploiting the environment faster than it could regenerate itself, they claimed, a situation that is clearly unsustainable.

This approach has many problems. Perhaps the most serious is its attempt to establish a necessary condition for the sustainability of human society in terms of the single dimension of biologically productive land area. For instance, to translate energy use into land units, Wackernagel and his colleagues calculated the area of forests that would be needed to absorb the carbon dioxide produced in generating the energy. This approach fails for energy generation technologies that do not emit carbon dioxide, such as solar panels, hydropower or nuclear plants. Converting all energy production to nuclear energy would change the dilemma from too much CO_2 to too much spent nuclear fuel. The problem of sustainability remains, but biologically productive land area is not a useful indicator of it.

Other one-dimensional quantities that have been proposed as ceilings on human carrying capacity include water, energy, food and various chemical elements required for food production. The difficulty with every single index of human carrying capacity is that its meaning depends on the value of other factors. If water is scarce and energy is abundant, for example, it is easy to desalinate and transport water; if energy is expensive, desalination and transport may be impractical.

Attempts to quantify Earth's human carrying capacity or a sustainable human population size face the challenge of understanding the constraints imposed by nature, the choices faced by people and the interactions between them. Some of the constraints imposed by nature are dealt with elsewhere in this issue. Here I will draw attention to the questions of human choice involved in assessing sustainability.

What will humans desire and what will they accept as the average level and distribution of material well-being in 2050 and beyond? What

BRYAN CHRISTIE DESIGN (*map*); JEN CHRISTIANSEN (*graphs*)

THE MIGRATION WILD CARD


New U.S. citizens

MIGRATION HAS LITTLE immediate effect on global population size but may accelerate the slowing of population growth. Migrants who move from high-fertility to low-fertility regions or their descendants often adopt the reduced-fertility patterns of their new home, with some time delay. From 2005 to 2050, the more developed regions are projected to have about 2.2 million more immigrants than emigrants a year, and the U.S. is expected to receive about half of these.

More than most demographic variables, future international migration is subject to intentional policy choices by national governments, making it difficult to predict. Assuming that recent levels of migration continue, the 98 million net migrants expected to move to the developed regions during 2005–2050 would more than offset the projected loss of 73 million people in those countries from an excess of deaths over births. Different international migration scenarios would not greatly affect the sharp rise in the rich countries' proportion of dependent elderly projected for the coming century, although they could dramatically affect population size.

In 2000, for example, the U.S. Census Bureau projected the nation's numbers in 2050 with different levels of immigration. Results ranged from 328 million, representing a 20 percent population increase with zero immigration, to 553 million, representing an 80 percent increase with the highest level of immigration—hypothetical net annual immigration rising to 2.8 million by 2050. Regardless of migration, though, the U.S. ratio of elderly to working-age people will rise steeply from 2010 until around 2035 and will gradually increase thereafter. By 2050 it is projected to reach 39 percent with zero immigration and 30 percent with the highest immigration. *—J.E.C.*

technologies will be used? What domestic and international political institutions will be used to resolve conflicts? What economic arrangements will provide credit, regulate trade, set standards and fund investments? What social and demographic arrangements will influence birth, health, education, marriage, migration and death? What physical, chemical and biological environments will people want to live in? What level of variability will people be willing to live with? (If people do not mind seeing human population size drop by billions when the climate becomes unfavorable, they may regard a much larger population as sustainable when the climate is favorable.) What level of risk are people willing to live with? (Are mud slides, hurricanes or floods acceptable risks or not? The answer will influence the area of land viewed as habitable.) What time horizon is assumed? Finally, and significantly, what will people's values and tastes be in the future? As anthropologist Donald L. Hardesty noted in 1977, "A plot of land may have a low carrying capacity, not because of low soil fertility but because it is sacred or inhabited by ghosts."

Most published estimates of Earth's human carrying capacity uncritically assumed answers to one or more of these questions. In my book *How Many People Can the Earth Support?* I collected and analyzed more than five dozen of these estimates published from 1679 onward. Those made in just the past half a century ranged from less than one billion to more than 1,000 billion. These estimates are political numbers, intended to persuade people, one way or another: either that too many humans are already on Earth or that there is no problem with continuing rapid population growth.

Scientific numbers are intended to describe reality. Because no estimates of human carrying capacity have explicitly addressed the questions raised above, taking into account the diversity of views about their answers in different societies and cultures, no scientific estimates of sustainable human population size can be said to exist.

Too often attention to long-term sustainability is a diversion from the immediate problem of making tomorrow better than today, a task that does offer much room for science and constructive action. Let us therefore briefly consider two major demographic trends, urbanization and aging, and some of the choices they present.

Boom or Bomb?

MANY MAJOR CITIES were established in regions of exceptional agricultural productivity, typically the floodplains of rivers, or in coastal zones and islands with favorable access to marine food resources and maritime commerce. If the world's urban population roughly doubles in the next half a century, from three billion to six billion, while the world's rural population remains roughly constant at three billion, and if many cities expand in area rather than increasing in density, fertile agricultural lands around those cities could be removed from production, and the waters around coastal or island cities could face a growing challenge from urban waste.

Right now the most densely settled half of the planet's population lives on 2 to 3 percent of all ice-free land. If cities double in area as well as population by 2050, urban areas could grow to occupy 6 percent of land. Withdrawing that amount mostly from the 10 to 15 percent of land considered arable could have a notable impact on agricultural production. Planning cities to avoid consuming arable land would greatly reduce the effect of their population growth on food produc-

SPENCER PLATT *Getty Images*

tion, a goal very much in the urbanites' interest because the cities will need to be provisioned.

Unless urban food gardening surges, on average each rural person will have to shift from feeding herself (most of the world's agricultural workers are women) and one city dweller today to feeding herself and two urbanites in less than half a century. If the intensity of rural agricultural production increases, the demand for food, along with the technology supplied by the growing cities to the rural regions, may ultimately lift the rural agrarian population from poverty, as happened in many rich countries. On the other hand, if more chemical fertilizers and biocides are applied to raise yields, the rise in food production could put huge strains on the environment.

One agricultural worker today feeds herself and one city dweller on average. In 2050 she will have to feed herself and two urbanites.

ERIK DE CASTRO *Reuters/Corbis*

For city dwellers, urbanization threatens frightening hazards from infectious disease unless adequate sanitation measures supply clean water and remove wastes. Yet cities also concentrate opportunities for educational and cultural enrichment, access to health care, and diverse employment. Therefore, if half the urban infrastructure that will exist in the world of 2050 must be built in the next 45 years, the opportunity to design, construct, operate and maintain new cities better than old ones is enormous, exciting and challenging.

Urbanization will interact with the transformation of human societies by aging. Cities raise the economic premium paid to younger, better-educated workers whereas the mobility they promote often weakens traditional kin networks that provide familial support to elderly people. An older, uneducated woman who could have familial support and productive work in agriculture if she lived in a rural area might have difficulty finding both a livelihood and social support in a city.

After 2010, most countries will experience a sharp acceleration in the rate of increase of the elderly dependency ratio—the ratio of the number of people aged 65 and older to the number aged 15 to 64. The shift will come first and most acutely in the more developed countries, whereas the least developed countries will experience a slow increase in elderly dependency after 2020. By 2050 the elderly dependency ratio of the least developed countries will approach that of the more developed countries in 1950.

Extrapolating directly from age to economic and social burdens is unreliable, however. The economic burden imposed by elderly people will depend on their health, on the economic institutions available to offer them work, and on the social institutions on hand to support their care.

Trends in the health of the elderly are positive overall, despite severe problems in some economies in transition and regions afflicted by AIDS. The rate of chronic disability among elderly Americans, for example, declined rapidly between 1982 and 1999. As a result, by 1999, 25 percent fewer elderly Americans were chronically disabled than would have been expected if the U.S. disability rate had remained constant since 1982.

Because an older person relies first on his or her spouse in case of difficulty (if there is a spouse), marital status is also a key influence on living conditions among the elderly. Married elderly people are more likely to be maintained at home rather than institutionalized compared with single, widowed or divorced persons.

The sustainability of the elderly population depends in complex ways not only on age, gender and marital status but also on the availability of supportive offspring and on socioeconomic status—notably educational attainment. Better education in youth is associated with better health in old age. Consequently, one obvious strategy to improve the sustainability of the coming wave of older people is to invest in educating youth today, including education in those behaviors that preserve health and promote the stability of marriage. Another obvious strategy is to invest in the economic and social institutions that facilitate economic productivity and social engagement among elderly people.

No one knows the path to sustainability because no one knows the destination, if there is one. But we do know much that we could do today to make tomorrow better than it would be if we do not put our knowledge to work. As economist Robert Cassen remarked, "Virtually everything that needs doing from a population point of view needs doing anyway." SA

MORE TO EXPLORE

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Population Reference Bureau: **www.prb.org/**

CAN EXTREME POVERTY BE ELIMINATED?

BY JEFFREY D. SACHS

Market economics and globalization are lifting the bulk of humanity out of extreme poverty, but special measures are needed to help the poorest of the poor

Almost everyone who ever lived was wretchedly poor. Famine, death from childbirth, infectious disease and countless other hazards were the norm for most of history. Humanity's sad plight started to change with the Industrial Revolution, beginning around 1750. New scientific insights and technological innovations enabled a growing proportion of the global population to break free of extreme poverty.

Two and a half centuries later more than five billion of the world's 6.5 billion people can reliably meet their basic living needs and thus can be said to have escaped from the precarious conditions that once governed everyday life. One out of six inhabitants of this planet, however, still struggles daily to meet some or all of such critical requirements as adequate nutrition, uncontaminated drinking water, safe shelter and sanitation as well as access to basic health care. These people get by on $1 a day or less and are overlooked by public services for health, education and infrastructure. Every day more than 20,000 die of dire poverty, for want of food, safe drinking water, medicine or other essential needs.

For the first time in history, global economic prosperity, brought on by continuing scientific and technological progress and the self-reinforcing accumulation of wealth, has placed the world within reach of eliminating extreme poverty altogether. This prospect will seem fanciful to some, but the dramatic economic progress made by China, India and other low-income parts of Asia over the past 25 years demonstrates that it is realistic. Moreover, the predicted stabilization of the world's population toward the middle of this century will help by easing pressures on Earth's climate, ecosystems and natural resources—pressures that might otherwise undo economic gains.

Although economic growth has shown a remarkable capacity to lift vast numbers of people out of extreme poverty, progress is neither automatic nor inevitable. Market forces and free trade are not enough. Many of the poorest regions are ensnared in a

EXTREME POVERTY could become a thing of the past in a few decades if the affluent countries of the world pony up a small percentage of their wealth to help the planet's 1.1 billion indigent populations out of conditions of dire poverty. At the right, a Ghanaian village is served by a single water standpipe.

IAN BERRY *Magnum Photos*

poverty trap: they lack the financial means to make the necessary investments in infrastructure, education, health care systems and other vital needs. Yet the end of such poverty is feasible if a concerted global effort is undertaken, as the nations of the world promised when they adopted the Millennium Development Goals at the United Nations Millennium Summit in 2000. A dedicated cadre of development agencies, international financial institutions, nongovernmental organizations and communities throughout the developing world already constitute a global network of expertise and goodwill to help achieve this objective.

This past January my colleagues and I on the U.N. Millennium Project published a plan to halve the rate of extreme poverty by 2015 (compared with 1990) and to achieve other quantitative targets for reducing hunger, disease and environmental degradation. In my recent book, *The End of Poverty,* I argue that a large-scale and targeted public investment effort could in fact eliminate this problem by 2025, much as smallpox was eradicated globally. This hypothesis is controversial, so I am pleased to have the opportunity to clarify its main arguments and to respond to various concerns that have been raised about it.

CROSSROADS FOR
POVERTY

THE PROBLEM:

- Much of humankind has succeeded in dragging itself out of severe poverty since the onset of the Industrial Revolution in the mid-18th century, but about 1.1 billion out of today's 6.5 billion global inhabitants are utterly destitute in a world of plenty.
- These unfortunates, who get by on less than $1 a day, have little access to adequate nutrition, safe drinking water and shelter, as well as basic sanitation and health care services. What can the developed world do to lift this huge segment of the human population out of extreme poverty?

THE PLAN:

- Doubling affluent nations' international poverty assistance to about $160 billion a year would go a long way toward ameliorating the terrible predicament faced by one in six humans. This figure would constitute about 0.5 percent of the gross national product (GNP) of the planet's rich countries. Because these investments do not include other categories of aid, such as spending on major infrastructure projects, climate change mitigation or postconflict reconstruction, donors should commit to reaching the long-standing target of 0.7 percent of GNP by 2015.
- These donations, often provided to local groups, would need to be closely monitored and audited to ensure that they are correctly targeted toward those truly in need.


Food for young African refugees

CHRIS STEELE-PERKINS *Magnum Photos*

Beyond Business as Usual

ECONOMISTS HAVE LEARNED a great deal during the past few years about how countries develop and what roadblocks can stand in their way. A new kind of development economics needs to emerge, one that is better grounded in science—a "clinical economics" akin to modern medicine. Today's medical professionals understand that disease results from a vast array of interacting factors and conditions: pathogens, nutrition, environment, aging, individual and population genetics, lifestyle. They also know that one key to proper treatment is the ability to make an individualized diagnosis of the source of illness. Likewise, development economists need better diagnostic skills to recognize that economic pathologies have a wide variety of causes, including many outside the traditional ken of economic practice.

Public opinion in affluent countries often attributes extreme poverty to faults with the poor themselves—or at least with their governments. Race was once thought the deciding factor. Then it was culture: religious divisions and taboos, caste systems, a lack of entrepreneurship, gender inequities. Such theories have waned as societies of an ever widening range of religions and cultures have achieved relative prosperity. Moreover, certain supposedly immutable aspects of culture (such as fertility choices and gender and caste roles) in fact change, often dramatically, as societies become urban and develop economically.

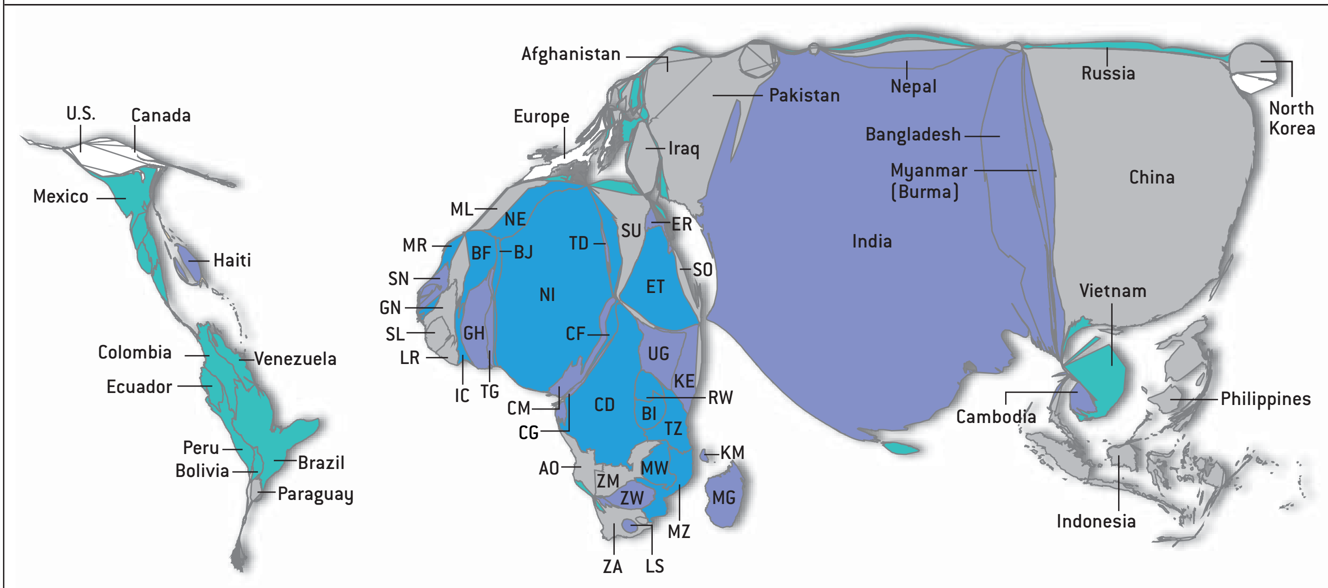
Most recently, commentators have zeroed in on "poor governance," often code words for corruption. They argue that extreme poverty persists because governments fail to open up their markets, provide public services and clamp down on bribe taking. It is said that if these regimes cleaned up their acts, they, too, would flourish. Development assistance efforts have become largely a series of good governance lectures.

The availability of cross-country and time-series data now allows experts to make much more systematic analyses. Although debate continues, the weight of the evidence indicates that governance makes a difference but is not the sole determinant of economic growth. According to surveys conducted by Transparency International, business leaders actually perceive many fast-growing Asian countries to be more corrupt than some slow-growing African ones.

Geography—including natural resources, climate, topography, and proximity to trade routes and major markets—is at least as important as good governance. As early as 1776, Adam Smith argued that high transport costs inhibited devel-

CHRONIC POVERTY: RICH WORLD, POOR PEOPLE

Although chronically poor people live in all regions of the world, they are concentrated in certain places. According to many studies, the problem of extreme poverty (those living on less than $1 a day) is least tractable in sub-Saharan Africa, the Andean and Central American highlands, and the landlocked nations of Central Asia. In the map below, produced by the Chronic Poverty Research Center, country size scales to the number of chronically poor people it harbors, and color indicates the income level of most impoverished inhabitants of each country. When sufficient official data were unavailable, the researchers estimated national poverty rates and numbers.



- Desperately poor
- Very poor
- Relatively nonpoor
- Insufficient data
- Industrial nations

Abbr.	Country Name	Abbr.	Country Name	Abbr.	Country Name	Abbr.	Country Name
AO	Angola	ET	Ethiopia	MW	Malawi	SO	Somalia
BF	Burkina Faso	GH	Ghana	ML	Mali	SU	Sudan
BI	Burundi	GN	Guinea	MR	Mauritania	TD	Chad
BJ	Benin	IC	Ivory Coast	MZ	Mozambique	TG	Togo
CD	Democratic Republic of the Congo	KE	Kenya	NE	Niger	TZ	Tanzania
CF	Central African Republic	KM	Comoros	NI	Nigeria	UG	Uganda
CG	Congo (Brazzaville)	LR	Liberia	RW	Rwanda	ZA	South Africa
CM	Cameroon	LS	Lesotho	SL	Sierra Leone	ZM	Zambia
ER	Eritrea	MG	Madagascar	SN	Senegal	ZW	Zimbabwe

SOURCE: CHRONIC POVERTY RESEARCH CENTER (WWW.CHRONICPOVERTY.ORG)

opment in the inland areas of Africa and Asia. Other geographic features, such as the heavy disease burden of the tropics, also interfere. One recent study by my Columbia University colleague Xavier Sala-i-Martin demonstrated once again that tropical countries saddled with malaria have experienced slower growth than those free from the disease. The good news is that geographic factors shape, but do not decide, a country's economic fate. Technology can offset them: drought can be fought with irrigation systems, isolation with roads and mobile telephones, diseases with preventive and therapeutic measures.

The other major insight is that although the most powerful mechanism for reducing extreme poverty is to encourage overall economic growth, a rising tide does not necessarily lift all boats. Average income can rise, but if the income is distributed unevenly the poor may benefit little, and pockets of extreme poverty may persist (especially in geographically disadvantaged regions). Moreover, growth is not simply a free-market phenomenon. It requires basic government services: infrastructure, health, education, and scientific and technological innovation. Thus, many of the recommendations of the past two decades emanating from Washington—that governments in low-income countries should cut back on their spending to make room for the private sector—miss the point. Government spending, directed at investment in critical areas, is itself a vital spur to growth, especially if its effects are to reach the poorest of the poor.

THE AUTHOR

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SACHS directs the Earth Institute at Columbia University and the United Nations Millennium Project. An economist, Sachs is well known for advising governments in Latin America, eastern Europe, the former Soviet Union, Asia and Africa on economic reforms and for his work with international agencies to promote poverty reduction, disease control and debt reduction in poor countries. A native of Detroit, he received his B.A., M.A. and Ph.D. degrees from Harvard University.

Q&A

GLOBALIZATION, POVERTY AND FOREIGN AID

Average citizens in affluent nations often have many questions about the effects of economic globalization on rich and poor nations and about how developing countries spend the aid they receive. Here are a few brief answers:

Is globalization making the rich richer and the poor poorer?

Generally, the answer is no. Economic globalization is supporting very rapid advances of many impoverished economies, notably in Asia. International trade and foreign investment inflows have been major factors in China's remarkable economic growth during the past quarter century and in India's fast economic growth since the early 1990s. The poorest of the poor, notably in sub-Saharan Africa, are not held back by globalization; they are largely bypassed by it.

Is poverty the result of exploitation of the poor by the rich?

Affluent nations have repeatedly plundered and exploited poor countries through slavery, colonial rule and unfair trade practices. Yet it is perhaps more accurate to say that exploitation is the result of poverty (which leaves impoverished countries vulnerable to abuse) rather than the cause of it. Poverty is generally the result of low productivity per worker, which reflects poor health, lack of job-market skills, patchiness of infrastructure (roads, power plants, utility lines, shipping ports), chronic malnutrition and the like. Exploitation has played a role in producing some of these conditions, but deeper factors (geographic isolation, endemic disease, ecological destruction, challenging conditions for food production) have tended to be more important and difficult to overcome without external help.

Will higher incomes in poor countries mean lower incomes in rich countries?

By and large, economic development is a positive-sum process, meaning that all can partake in it without causing some to suffer. In the past 200 years, the world as a whole has achieved a massive increase in economic output rather than a shift in economic output to one region at the expense of another. To be sure, global environmental constraints are already starting to impose themselves. As today's poor countries develop, the climate, fisheries and forests are coming under increased strain. Overall global economic growth is compatible with sustainable management of the ecosystems on which all humans depend—indeed, wealth can be good for the environment—but only if public policy and technologies encourage sound practices and the necessary investments are made in environmental sustainability.

Do U.S. private contributions make up for the low levels of U.S. official aid?

Some have claimed that while the U.S. government budget provides relatively little assistance to the poorest countries, the private sector makes up the gap. In fact, the Organization for Economic Cooperation and Development has estimated that private foundations and nongovernmental organizations give roughly $6 billion a year in international assistance, or 0.05 percent of U.S. gross national product (GNP). In that case, total U.S. international aid is around 0.21 percent of GNP—still among the lowest ratios of all donor nations. *—J.D.S.*

The Poverty Trap

SO WHAT DO THESE INSIGHTS tell us about the region most afflicted by poverty today, Africa? Fifty years ago tropical Africa was roughly as rich as subtropical and tropical Asia. As Asia boomed, Africa stagnated. Special geographic factors have played a crucial role.

Foremost among these is the existence of the Himalaya Mountains, which produce southern Asia's monsoon climate and vast river systems. Well-watered farmlands served as the starting points for Asia's rapid escape from extreme poverty during the past five decades. The Green Revolution of the 1960s and 1970s introduced high-yield grains, irrigation and fertilizers, which ended the cycle of famine, disease and despair.

It also freed a significant proportion of the labor force to seek manufacturing jobs in the cities. Urbanization, in turn, spurred growth, not only by providing a home for industry and innovation but also by prompting greater investment in a healthy and skilled labor force. Urban residents cut their fertility rates and thus were able to spend more for the health, nutrition and education of each child. City kids went to school at a higher rate than their rural cousins. And with the emergence of urban infrastructure and public health systems, city populations became less disease-prone than their counterparts in the countryside, where people typically lack safe drinking water, modern sanitation, professional health care and protection from vector-borne ailments such as malaria.

Africa did not experience a green revolution. Tropical Africa lacks the massive floodplains that facilitate the large-scale and low-cost irrigation found in Asia. Also, its rainfall is highly variable, and impoverished farmers have been unable to purchase fertilizer. The initial Green Revolution research featured crops, especially paddy rice and wheat, not widely grown in Africa (high-yield varieties suitable for it have been developed in recent years, but they have not yet been disseminated sufficiently). The continent's food production per person has actually been falling, and Africans' caloric intake is the lowest in the world; food insecurity is rampant. Its labor force has remained tethered to subsistence agriculture.

EMILY HARRISON

Compounding its agricultural woes, Africa bears an overwhelming burden of tropical diseases. Because of climate and the endemic mosquito species, malaria is more intensively transmitted in Africa than anywhere else. And high transport costs isolate Africa economically. In East Africa, for example, the rainfall is greatest in the interior of the continent, so most people live there, far from ports and international trade routes.

Much the same situation applies to other impoverished parts of the world, notably the Andean and Central American highlands and the landlocked countries of Central Asia. Being economically isolated, they are unable to attract much foreign investment (other than for the extraction of oil, gas and precious minerals). Investors tend to be dissuaded by the high transport costs associated with the interior regions. Rural areas therefore remain stuck in a vicious cycle of poverty, hunger, illness and illiteracy. Impoverished areas lack adequate internal savings to make the needed investments because most households live hand to mouth. The few high-income families, who do accumulate savings, park them overseas rather than at home. This capital flight includes not only financial capital but also the human variety, in the form of skilled workers—doctors, nurses, scientists and engineers, who frequently leave in search of improved economic opportunities abroad. The poorest countries are often, perversely, net exporters of capital.

Put Money Where Mouths Are

THE TECHNOLOGY TO OVERCOME these handicaps and jump-start economic development exists. Malaria can be controlled using bed nets, indoor pesticide spraying and improved medicines. Drought-prone countries in Africa with nutrient-depleted soils can benefit enormously from drip irrigation and greater use of fertilizers. Landlocked countries can be connected by paved highway networks, airports and fiber-optic cables. All these projects cost money, of course.

Many larger countries, such as China, have prosperous regions that can help support their own lagging areas. Coastal eastern China, for instance, is now financing massive public investments in western China. Most of today's successfully developing countries, especially smaller ones, received at least some backing from external donors at crucial times. The critical scientific innovations that formed the underpinnings of the Green Revolution were bankrolled by the Rockefeller Foundation, and the spread of these technologies in India and elsewhere in Asia was funded by the U.S. and other donor governments and international development institutions.

We in the U.N. Millennium Project have listed the investments required to help today's impoverished regions cover basic needs in health, education, water, sanitation, food production, roads and other key areas. We have put an approximate price tag on that assistance and estimated how much could be financed by poor households themselves and by domestic institutions. The remaining cost is the "financing gap" that international donors need to make up.

For tropical Africa, the total investment comes to $110 per person a year. To place this into context, the average income

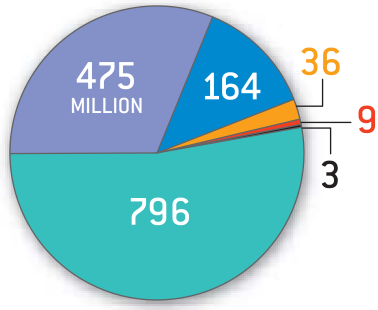
EXTREME POVERTY: WHERE WE STAND

The number of people mired in the lowest depths of poverty has shrunk since the early 1980s, as the global economy has grown stronger. But these gains were concentrated in East Asia, leaving behind more than a billion unfortunates in sub-Saharan Africa, Central Asia and the mountainous parts of Central America and the Andean region. A determined push to help those lagging populations during the coming decade could cut the ranks of poor in half. The numbers below indicate millions of people.

Latin America and the Caribbean
Middle East and North Africa
Europe and Central Asia
East Asia and the Pacific
South Asia
Sub-Saharan Africa

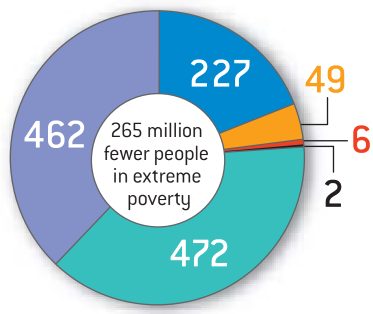
1981:
1.5 Billion Poor

Greater than half those living in extreme poverty were in East Asia and over a quarter in South Asia



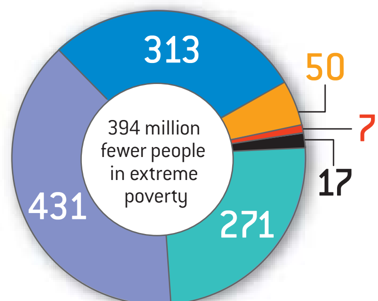
1990:
1.2 Billion Poor

The number of extremely poor people in East Asia shrank by 278 million. Had poverty rates there not fallen, population growth would have added 285 million to the ranks of the severely poor



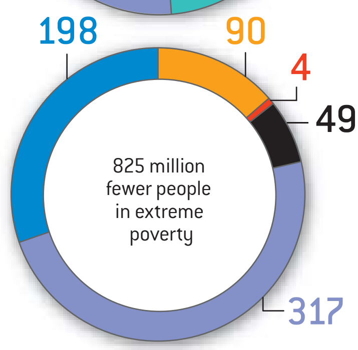
2001:
1.1 Billion Poor

Some 129 million fewer people were living in extreme poverty than in 1990, but the numbers of the extreme poor in sub-Saharan Africa rose to 313 million—one third of the global total



2015:
0.7 Billion Poor

Achieving the Millennium Development Goals will mean that by 2015 more than 500 million people will be lifted out of extreme poverty as compared with 1990 and that millions of lives will be saved



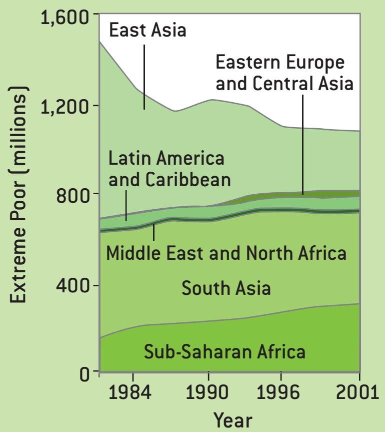
JEN CHRISTIANSEN; SOURCE: WORLD BANK GROUP'S WORLD DEVELOPMENT INDICATORS (WWW.WORLDBANK.ORG/DATA/WDI2005/WDITEXT/SECTION1_1_1.HTM)

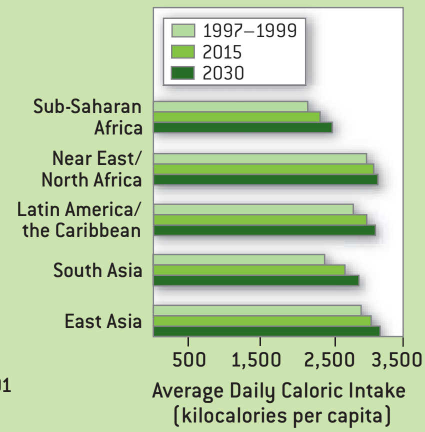
THE MILLENNIUM DEVELOPMENT GOALS: HOW ARE WE DOING?

At the United Nations Millennium Summit in 2000, the nations of the world promised to make the investments necessary to help today's impoverished regions improve their residents' welfare in key areas, including health, education, water, sanitation and food production. The U.N. specified eight broad Millennium Development Goals (MDG) to reduce extreme poverty substantially across the globe by 2015. The data on these two pages illustrate the challenges of meeting those goals. Measurement of progress is based on statistical levels that existed in 1990.

GOAL 1 ERADICATE EXTREME POVERTY AND HUNGER

Target: Halve the proportion of people living on less than $1 a day and the proportion of those who suffer chronic hunger.
Status: Between 1990 and 2001, the fraction of the populations in sub-Saharan Africa, Latin America and the Caribbean living in extreme poverty remained stagnant and, ominously, increased in Central Asia. Food intake is rising, but hunger is still widespread in several regions.





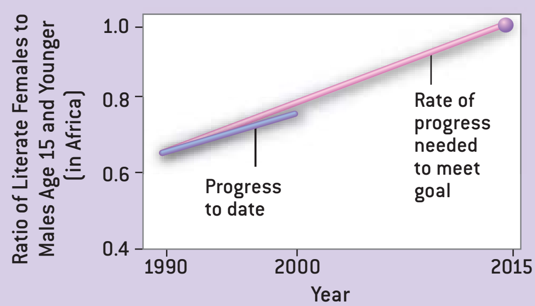
GOAL 2 ACHIEVE UNIVERSAL PRIMARY EDUCATION

Target: Ensure that by 2015 all children complete a full course of primary education.

GOAL 3 PROMOTE GENDER EQUALITY AND EMPOWER WOMEN

Target: Eliminate gender disparity in primary, secondary and tertiary education by 2015.

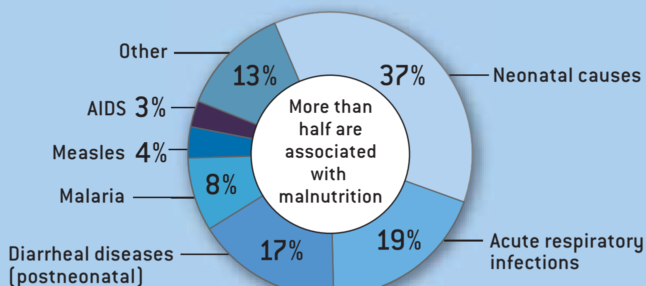
Status: Education is probably the best way to promote gender equality. The greatest challenges are in sub-Saharan Africa, where overall school completion rates have hovered around 50 percent. Women and girls fare even worse, as shown below by the ratio of literate females to males on the African continent.

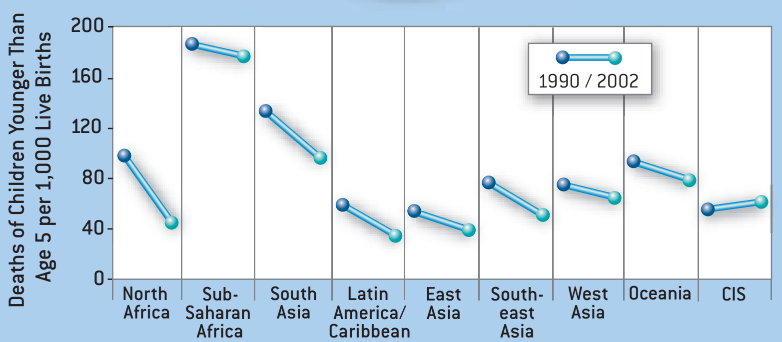


GOAL 4 REDUCE CHILD MORTALITY

Target: Reduce by two thirds the mortality rate of children younger than five years.
Status: Child mortality rates fell in every region except the former Soviet republics in the Commonwealth of Independent States (CIS), but rates remain high in sub-Saharan Africa and in South Asia. For comparison, the child mortality rate in high-income countries in 2000 was about six per 1,000 births.

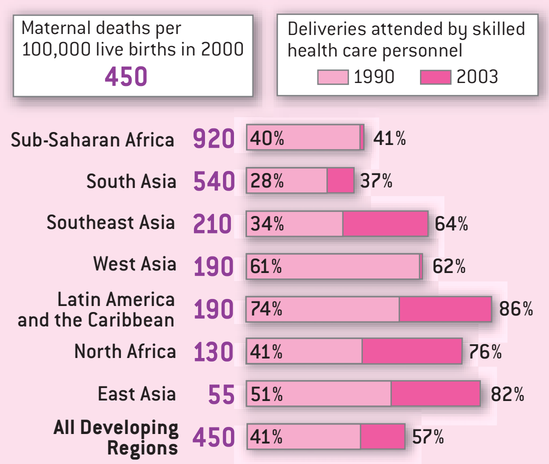
Causes of Death among Children Younger Than Age 5, from 2000–2003





GOAL 5 IMPROVE MATERNAL HEALTH

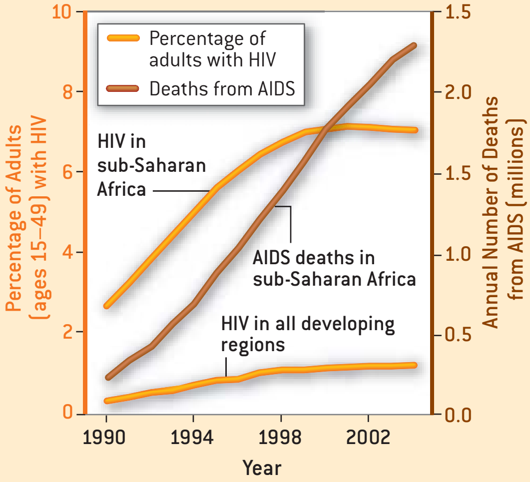
Target: Reduce by 75 percent the maternal mortality rate by 2015.
Status: Maternal mortality rates remain shockingly high in every developing region of the world. Increasing the proportion of deliveries attended by skilled health workers will be critical to lowering maternal mortality.

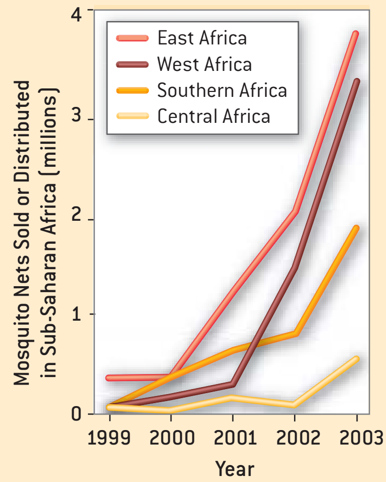


SARA BEARDSLEY (*data compilation*); JEN CHRISTIANSEN (*illustrations*); SOURCES: GOAL 1: WWW.WORLDBANK.ORG/DATA/WDI2005/WDITEXT/SECTION1_1_1.HTM (*graph*); WWW.FAO.ORG/DOCREP/007/Y5650E/Y5650E04.HTM (*bar chart*); GOALS 2 AND 3: *ACHIEVING THE MILLENNIUM DEVELOPMENT GOALS IN AFRICA*, JUNE 2002 (*graph*); GOAL 4: *THE MDG REPORT 2005* (*pie chart*); HTTP://UNSTATS.UN.ORG/UNSD/MI/MI_COVERFINAL.HTM (*line graph*); GOAL 5: *THE MDG REPORT 2005* (*bar chart*)

GOAL 6 COMBAT HIV/AIDS, MALARIA AND OTHER DISEASES

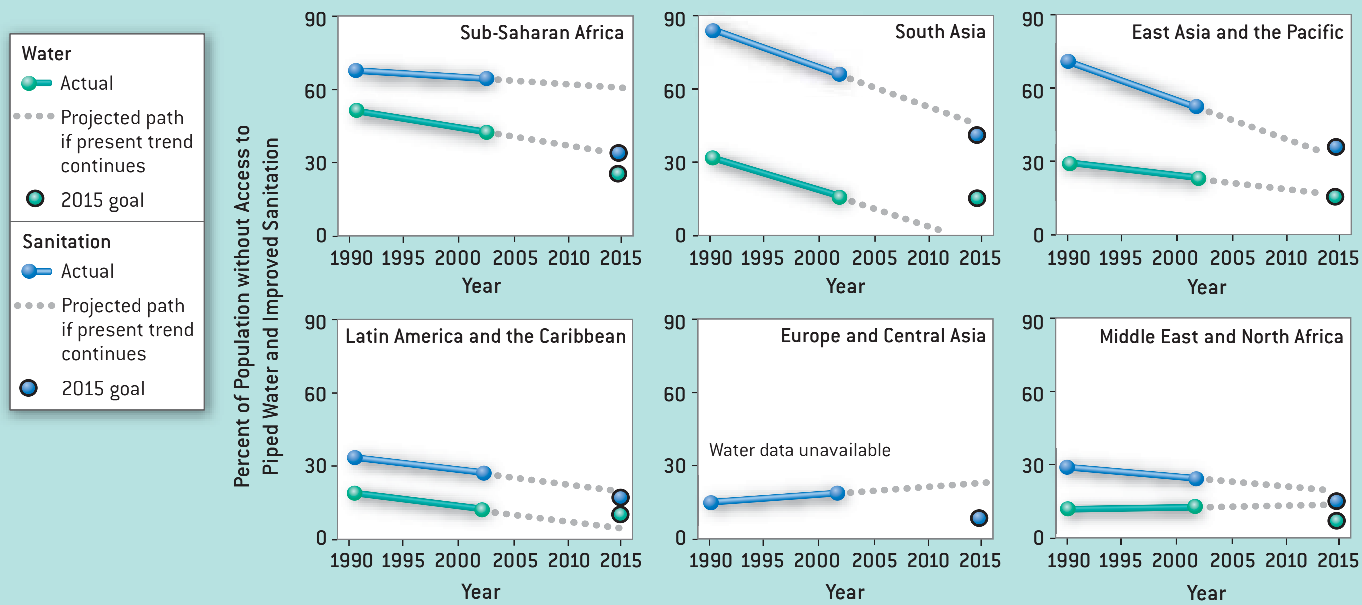
Targets: Halt and begin to reverse the spread of HIV/AIDS. Slow the spread of malaria and other diseases.
Status: HIV, now affecting about 40 million people, is widespread in parts of sub-Saharan Africa and poses a serious threat to other developing regions. Meanwhile malaria kills around three million people a year, mostly in Africa, the vast majority of them children. In recent years, the distribution of mosquito nets has expanded, but hundreds of millions in malarious regions still need nets.





GOAL 7 ENSURE ENVIRONMENTAL SUSTAINABILITY

Target: Halve by 2015 the proportion of people without sustainable access to safe drinking water and basic sanitation.
Status: With the exception of sub-Saharan Africa, access to drinking water in urban areas is generally relatively high, although rural access remains limited. Low availability of sanitation services in sub-Saharan African and South Asia contributes to widespread diarrheal disease.



GOAL 8 DEVELOP A GLOBAL PARTNERSHIP FOR DEVELOPMENT

Target: Address the special needs of the least developed countries (including more generous development assistance).
Status: Rich countries have repeatedly pledged to give 0.7 percent of their national income as foreign aid, yet 17 of 22 donors have failed to reach that target. Some progress has occurred, however: European Union countries recently committed to attaining the 0.7 percent mark by 2015. Meanwhile other donors claim that poor countries are too corrupt to achieve economic growth. The table at the right helps to dispel that myth; in fact, many fast-growing Asian economies have higher levels of perceived corruption than some slow-growing African ones.

CORRUPTION AND ECONOMIC GROWTH

		Rank of perceived corruption levels (lower means less corrupt)	Average yearly percent growth in GDP per capita, 1980–2000
Sub-Saharan Africa	Ghana	70	0.3
	Senegal	76	0.5
	Mali	78	–0.5
	Malawi	83	0.2
East Asia	India	83	3.5
	Pakistan	92	2.4
	Indonesia	122	3.5
	Bangladesh	133	2.0

GOAL 6: *THE MDG REPORT 2005* (*graphs*); GOAL 7: *GLOBAL MONITORING REPORT 2005: MDG: FROM CONSENSUS TO MOMENTUM* (*data*); GOAL 8: *GLOBAL CORRUPTION REPORT*, BY TRANSPARENCY INTERNATIONAL, 2004 (*table*)

in this part of the world is $350 per annum, most or all of which is required just to stay alive. The full cost of the total investment is clearly beyond the funding reach of these countries. Of the $110, perhaps $40 could be financed domestically, so that $70 per capita would be required in the form of international aid.

Adding it all up, the total requirement for assistance across the globe is around $160 billion a year, double the current rich-country aid budget of $80 billion. This figure amounts to approximately 0.5 percent of the combined gross national product (GNP) of the affluent donor nations. It does not include other humanitarian projects such as postwar Iraqi reconstruction or Indian Ocean tsunami relief. To meet these needs as well, a reasonable figure would be 0.7 percent of GNP, which is what all donor countries have long promised but few have fulfilled. Other organizations, including the International Monetary Fund, the World Bank and the British government, have reached much the same conclusion.

We believe these investments would enable the poorest countries to cut poverty by half by 2015 and, if continued, to eliminate it altogether by 2025. They would not be "welfare payments" from rich to poor but instead something far more important and durable. People living above mere subsistence levels would be able to save for their futures; they could join the virtuous cycle of rising incomes, savings and technological inflows. We would be giving a billion people a hand up instead of a handout.

If rich nations fail to make these investments, they will be called on to provide emergency assistance more or less indefinitely. They will face famine, epidemics, regional conflicts and the spread of terrorist havens. And they will condemn not only the impoverished countries but themselves as well to chronic political instability, humanitarian emergencies and security risks.

The debate is now shifting from the basic diagnosis of extreme poverty and the calculations of financing needs to the practical matter of how assistance can best be delivered. Many people believe that aid efforts failed in the past and that care is needed to avoid the repetition of failure. Some of these concerns are well grounded, but others are fueled by misunderstandings.

When pollsters ask Americans how much foreign aid they think the U.S. gives, they greatly overestimate the amount—by as much as 30 times. Believing that so much money has been donated and so little has been done with it, the public concludes that these programs have "failed." The reality is rather different. U.S. official assistance to sub-Saharan Africa has been running at $2 billion to $4 billion a year, or roughly $3 to $6 for every African. Most of this aid has come in the form of "technical cooperation" (which goes into the pockets of consultants), food contributions for famine victims and the cancellation of unpaid debts. Little of this support has come in a form that can be invested in systems that improve health, nutrition, food production and transport. We should give foreign aid a fair chance before deciding whether it works or not.

A second common misunderstanding concerns the extent to which corruption is likely to eat up the donated money. Some foreign aid in the past has indeed ended up in the equivalent of Swiss bank accounts. That happened when the funds were provided for geopolitical reasons rather than development; a good example was U.S. support for the corrupt regime of Mobutu Sese Seko of Zaire (now the Democratic Republic of the Congo) during part of the cold war. When assistance has been targeted at development rather than political goals, the outcomes have been favorable, ranging from the Green Revolution to the eradication of smallpox and the recent near-eradication of polio.

The aid package we advocate would be directed toward those countries with a reasonable degree of good governance and operational transparency. In Africa, these countries include Ethiopia, Ghana, Mali, Mozambique, Senegal and Tan-

Hungry children in Sudan

KENT KLICH *Magnum Photos*

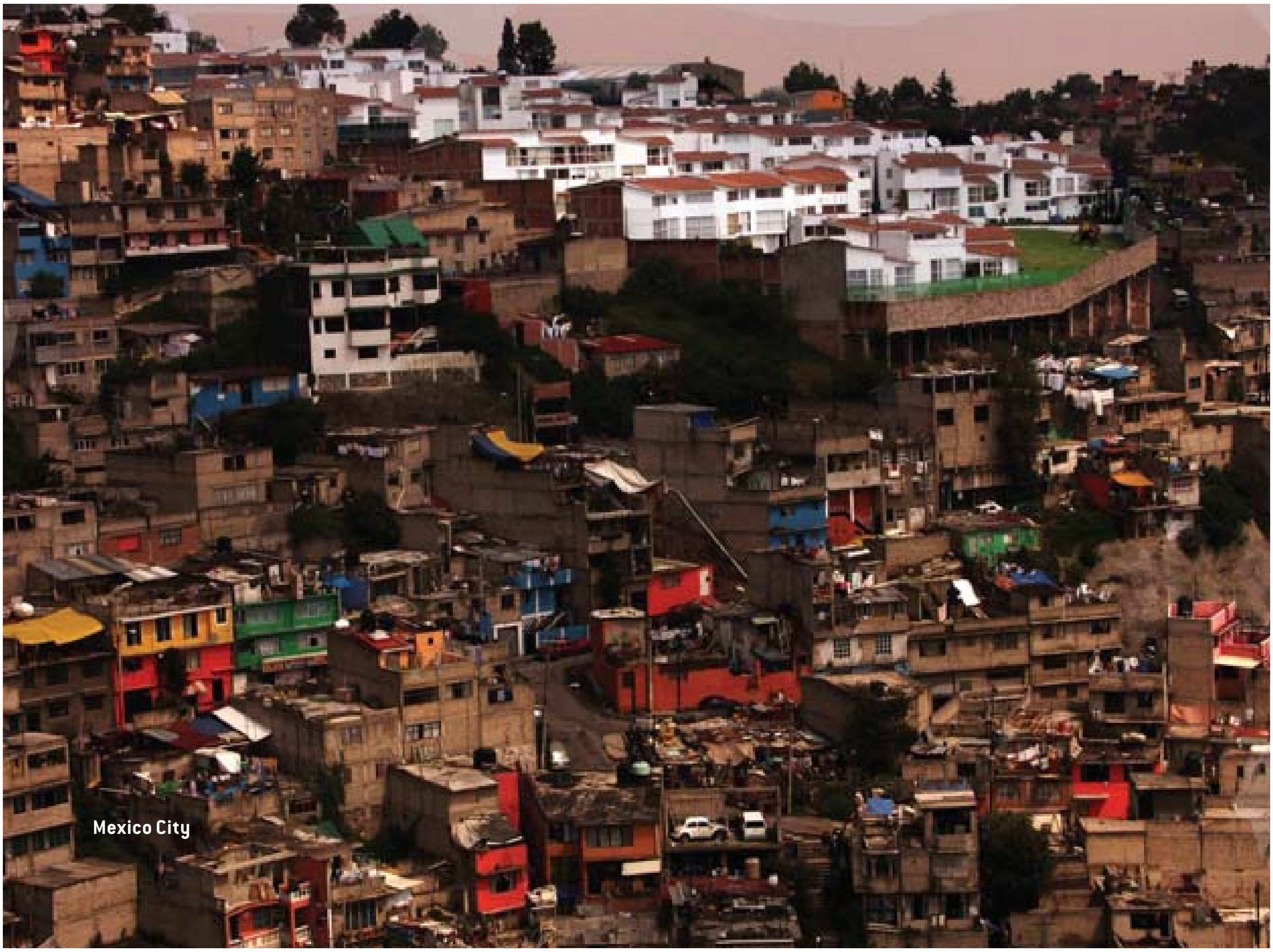
When polled, Americans greatly overestimate how much foreign aid the U.S. gives—by as much as 30 times.

FOREIGN AID: HOW SHOULD THE MONEY BE SPENT?

Here is a breakdown of the needed investment for three typical low-income African countries to help them achieve the Millennium Development Goals. For all nations given aid, the average total annual assistance per person would come to around $110 a year. These investments would be financed by both foreign aid and the countries themselves.

Investment Area	Average per Year between 2005–2015 ($ per capita)		
	Ghana	Tanzania	Uganda
Hunger	7	8	6
Education	19	14	15
Gender equality	3	3	3
Health	25	35	34
Water supply and sanitation	8	7	5
Improving slum conditions	2	3	2
Energy	15	16	12
Roads	10	22	20
Other	10	10	10
Total	**100**	**117**	**106**

Calculated from data from Investing in Development *(U.N. Millennium Project, Earthscan Publications, 2005). Numbers do not sum to totals because of rounding.*



"RICH MAN ON TOP, poor man below" describes the state of human society since the dawn of civilization, but the realization that all people on this planet are profoundly interdependent means that for the sake of our future, no one—not even the poorest among us—can be left behind.

zania. The money would not be merely thrown at them. It would be provided according to a detailed and monitored plan, and new rounds of financing would be delivered only as the work actually got done. Much of the funds would be given directly to villages and towns to minimize the chances of their getting diverted by central governments. All these programs should be closely audited.

Western society tends to think of foreign aid as money lost. But if supplied properly, it is an investment that will one day yield huge returns, much as U.S. assistance to western Europe and East Asia after World War II did. By prospering, today's impoverished countries will wean themselves from endless charity. They will contribute to the international advance of science, technology and trade. They will escape political instability, which leaves many of them vulnerable to violence, narcotics trafficking, civil war and even terrorist takeover. Our own security will be bolstered as well. As U.N. Secretary-General Kofi Annan wrote earlier this year: "There will be no development without security, and no security without development." SA

MONICA TERRAZAS *Galvan/UNEP/Peter Arnold*

MORE TO EXPLORE

Institutions Matter, but Not for Everything. Jeffrey D. Sachs in *Finance and Development (IMF),* Vol. 40, No. 2, pages 38–41; June 2003. www.sachs.earth.columbia.edu

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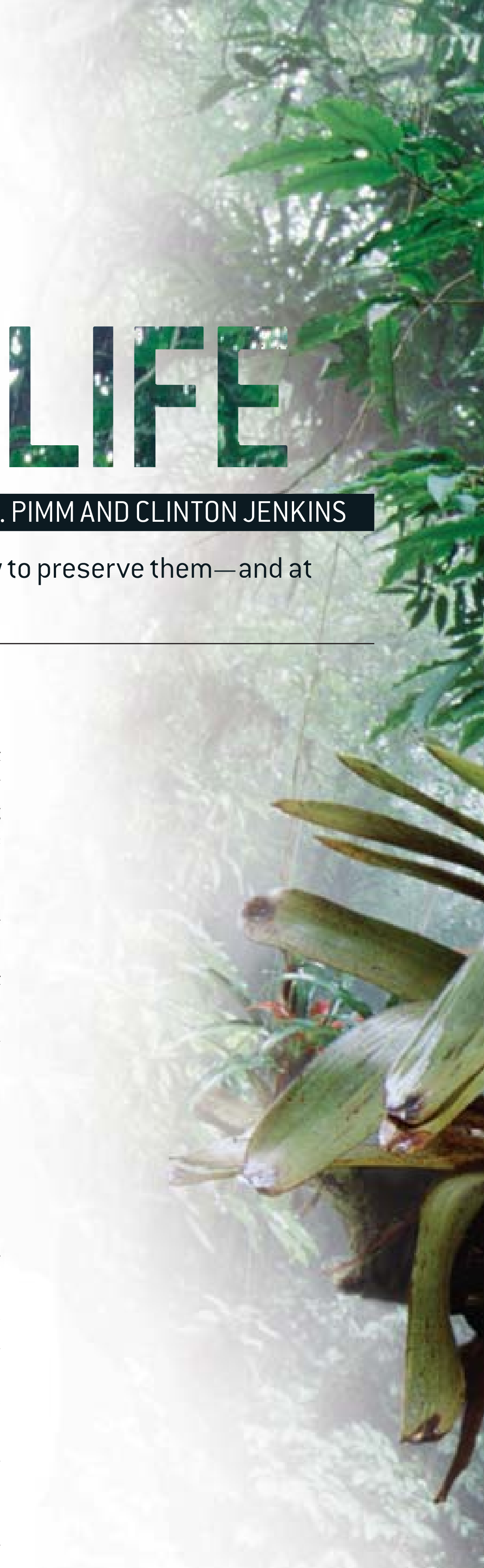
SUSTAINING THE VARIETY OF LIFE

BY STUART L. PIMM AND CLINTON JENKINS

A new understanding of how species become extinct suggests how to preserve them—and at a cost that doesn't break the bank



We stand in warm rain on a dirt road and contemplate a cattle pasture. It forms a 100-meter-wide gap, a kilometer long, between two patches of forest. Here, a few hours drive from Rio de Janeiro, our generation will make decisions that will determine whether we can sustain the present variety of life on Earth—its biodiversity. Brazil once had more than one million square kilometers of coastal forest. In the remaining 10 percent lives the largest number of species at immediate risk of extinction in the Americas.

The "we" who stand in the rain are the two of us plus our Brazilian colleague Maria Alice Alves, an ecologist from Rio de Janeiro's State University. Present, too, is the rancher who cleared the forest for his cattle, thinking that it was the best way to make money, and a representative from a local NGO (nongovernmental organization), who wants to restore the forest. We scientists might convince the international community to support that effort, but it is the three Brazilians, representing millions of others, who will actually decide their country's balance between cattle ranching and environmental stewardship.

In this pasture, and across the land and oceans, Earth is poised to become irreversibly poorer. Nothing can bring extinct species back. We do not live in Jurassic Park. Elsewhere, it is too late. In upland Hawaii, we have shivered in cold rain, vainly looking for birds with strange-sounding names—and stranger beaks. The *'akialoa, 'o'u* and *nukupu'u* were last spotted decades ago. The *po'o uli* likely expired as we wrote this article. Visiting remote places is not necessary to sense the changes; the nearest fishmonger suffices. If you once served orange roughy for dinner, that fact dates you more accurately than buying a recording by Madonna. The fishery opened in the early 1980s but collapsed within the decade. Fishing has massively depleted most of the major fish populations worldwide.

"Isn't extinction a natural process?" you ask. "Certainly!" we reply. Most species eventually become extinct. Extinction would not provoke concern if it simply ticked along at a natural rate. Fossils and molecular traces of evolutionary lineages show that species "tick over"—they are born and die—on a million-year timescale. (The exceptions are during the five mass extinction events that eliminated dinosaurs, trilobites and many others.) Herein lies an analogy: We humans live for 75 years or so. In a sample of 75 people, one expects one death a year and, in a sample of seven people, one in about a decade. Taking a million years for a species' lifetime, one expects one in a million to go extinct naturally each year. Equivalently, of the 10,000 known species of bird, one should become extinct every century. The actual rate is a very unnatural one every *year*—100 times higher.

PRESERVING some two dozen scientifically determined locations, such as this coastal rain forest near Rio de Janeiro, Brazil, would go a long way toward maintaining Earth's biodiversity.

Extinctions of all well-known animals and plants are similarly unnatural. They share another feature: their cause is human actions, including hunting, the introduction of exotic species (such as rats and weedy plants) and especially the destruction of species' habitats. Other threats are coming: global warming poses a danger to biodiversity perhaps equal to—and additional to—habitat loss.

For reasons we will explain later, some species are much more vulnerable than others, and they are geographically concentrated. Unnatural rates of extinction arise when human actions collide with these concentrations. That is why we are in a cattle pasture in Brazil or a cloud forest in Hawaii and not a cornfield in Iowa. To sustain the variety of life, one must deal with special places. This creates opportunities, as well as problems. Among the latter is that the special places are mostly in developing countries across the world's tropics.

"Haven't we developed as we've used up our natural resources?" you may ask, implying that humanity might be better off despite—and perhaps because of—the loss of species. "Who are we to deny progress to poorer countries?" Too often the developed countries did not benefit from destroying their own resources. The world's rich are often unaware of the massive taxes they pay to subsidize ecologically destructive activities. We lose both nature and money at the same time. Nor will the world's poor always benefit. For instance, they get much of their protein from fish. They cannot eat fish from the far side of the planet when their local fishery fails. They also depend on the free services the nearby forest provides—fuel, food, freshwater.

To sustain biodiversity, the world must first identify, then immediately protect the special places. In doing so, we must answer other questions. Can we eat and have biodiversity, too? Yes! Does saving species require humanity to revert to a preindustrial lifestyle? No! Certainly the costs of sustaining biodiversity are large. So, too, are the benefits.

The Geography of Unnatural Extinction

HIGH RATES OF EXTINCTION are not everywhere; they are in unexpected places. Intuition suggests that extinctions will occur where more people live and where more species live (because more will be at risk). That intuition is wrong. Human actions dominate eastern North America and Europe, but these regions have few extinctions. There are also few in the places where the most species live, such as the Amazon basin. Extinction black spots include almost all species on islands, mammals in Australia, plants in the southern tip of Africa, and freshwater fish in the Mississippi basin and East African lakes.

Four laws of biogeography explain these odd patterns [*see box on opposite page*]. Nature has created an unusually large number of "eggs" (very vulnerable species), placed them in a very few baskets and put them in harm's way.

Clearing a forest, draining a wetland, damming a river or dynamiting a coral reef to kill its fish can more readily eliminate species with small ranges than more widespread species. The first law says that there are usually many such vulnerable species. In everyday experience, "on average" is commonplace—in a group of people, most are near average height. Not so species ranges: if they were people, then most would be very short with a few professional basketball players thrown in for variety.

The second law makes the situation worse, because the vulnerable species with small ranges are usually locally rare—making them even more vulnerable. Law 3 shows that the world's tropical forests hold the greatest number of species—and these forests are shrinking rapidly. Law 4 shows that it gets even worse: the vulnerable species live in—they are endemic to—only a few, special tropical forests. The laws generate the observed pattern: extinctions occur where fronts of habitat destruction—principally deforestation—meet concentrations of vulnerable species.

Probably half the world's species live in some 25, mostly forested, tropical areas, where human actions have already removed more than 70 percent of the natural vegetation. This combination of high numbers of vulnerable species and high rates of habitat destruction defines these areas as what our Duke University colleague Norman Myers calls "hot spots" [*see box on pages 70 and 71*]. Researchers know less about the

CROSSROADS FOR BIODIVERSITY

THE PROBLEM:

- Extinction rates of animals and plants are much higher than we would expect from fossil and molecular evidence, approaching 1,000 times higher than the benchmark. Earth is poised to become irreversibly poorer because of these disappearances.

THE PLAN:

- To sustain biodiversity, we must immediately protect special places where the most species are at risk. These have been identified as 25 "hot spots" around the globe and areas of wilderness forest.

Photographs throughout the article show rare species from the world's hot spots.

Slender loris, Sri Lanka

TUI DE ROY *Minden Pictures* (*preceding pages*); MITSUAKI IWAGO *Minden Pictures* (*this page*)

THE LAWS OF BIOGEOGRAPHY

Ecological laws are patterns that hold globally and for many different groups of species. Four such laws describe where species live and how abundant they are.

LAW 1. Most species' ranges are very small; few are very large. One in 10 birds, one in six mammals, and over half of all amphibians have ranges smaller than the state of Connecticut. Most birds and mammals and almost all amphibians have ranges smaller than the states of California, Oregon and Washington combined. Familiar birds of town and country, such as cardinals, grackles and cowbirds, have exceptionally large ranges.

LAW 2. Species with small ranges are locally scarce. For birds, a third of those that have Connecticut-size ranges are "rare"—it takes several days of fieldwork to find one. Only a few are "common"—one sees them on every trip. Almost all species with ranges approximately the size of North America are common.

LAW 3. The number of species found in an area of given size varies greatly and according to some common factors. For example, the Arctic has few species and the tropics many.

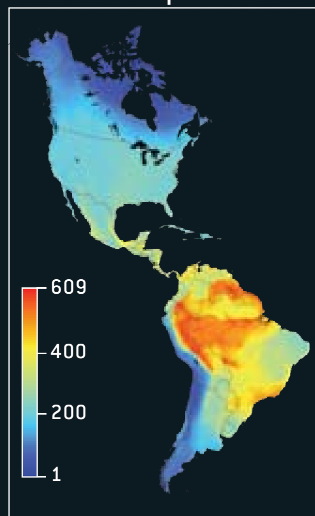
LAW 4. Species with small ranges are often geographically concentrated.

The numbers of bird and amphibian species, in an example of Law 3, vary by more than 100-fold from the tundras of northern Canada to the forests of the Amazon.

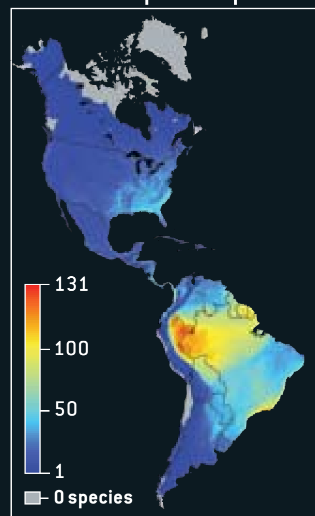
Glass frog, Central and South America

Small-ranged species often do not live in areas that are otherwise rich in species. The Amazon, for example, has almost no species with small ranges, whereas the forests along the base of the Andes and in coastal Brazil have many, as law 4 suggests. Small ranges are those that fall below the median size for a group of species.

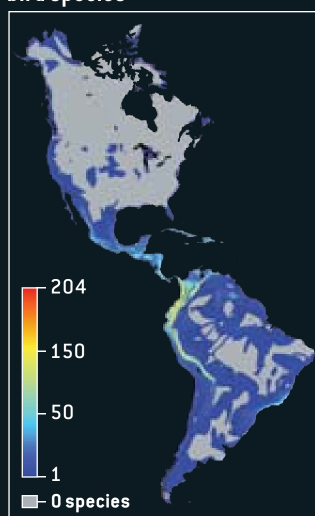
Number of bird species



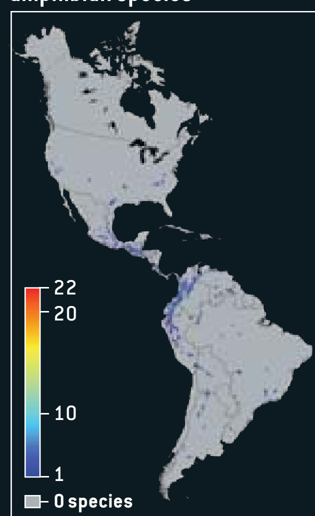
Number of amphibian species



Number of small-ranged bird species



Number of small-ranged amphibian species



oceans, but they, too, have similar concentrations of species with small ranges. These concentrations lie in coral reef ecosystems that, like their terrestrial counterparts, fall in the direct path of human actions.

Substantial tracts of intact wilderness remain: humid tropical forests such as the Amazon and Congo, drier woodlands of Africa, and coniferous forests of Canada and Russia. If deforestation in these wilderness forests continues at current rates, the combined extinction rate in them and in the hot spots will soon be 1,000 times higher than the benchmark "one in a million."

Finding Solutions for Special Places

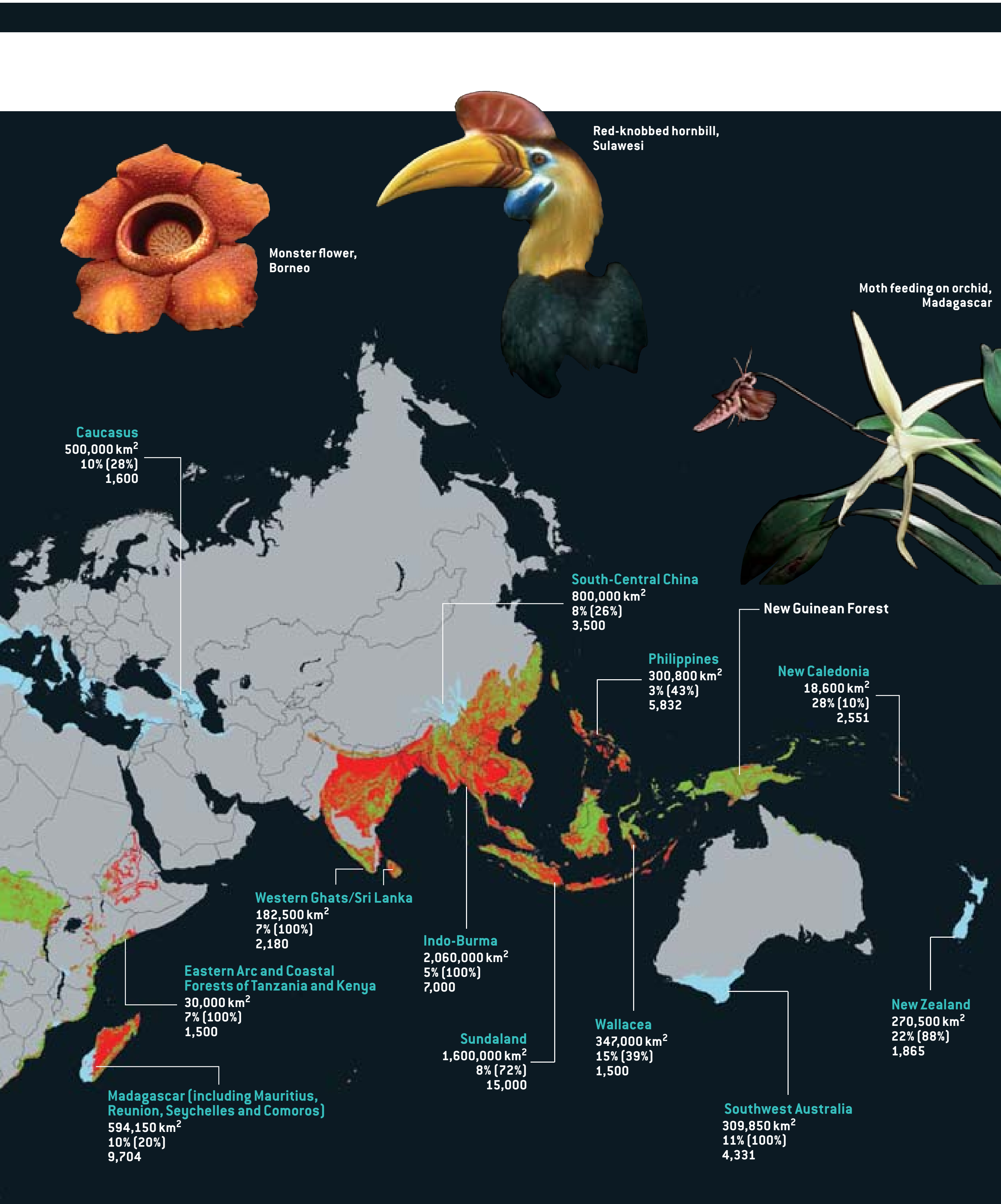
HAVING DECIDED ON the areas to protect, how should the world accomplish the task? In particular, who will pay for the protection? Developed countries are the obvious source, but the solution is complicated. Most of the wilderness forests and 25 hot spots were once European colonies. (New Caledonia remains a French territory.) These now independent countries need not look favorably on efforts by former colonials to "save" their forests. Understandably, they often view their forests as sources of income rather than as future national parks.

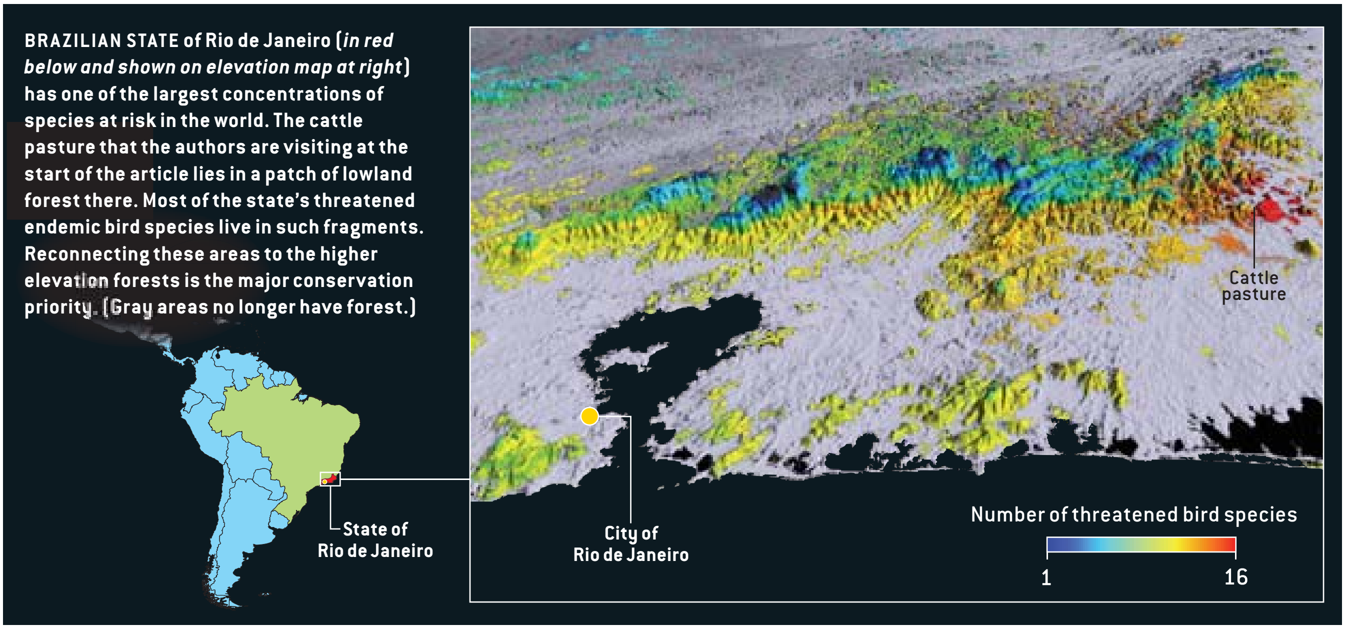
Selling logging leases does provide income for cash-poor

BIRD DATA FROM NATURESERVE IN COLLABORATION WITH ROBERT RIDGELY, JAMES ZOOK, THE NATURE CONSERVANCY–MIGRATORY BIRD PROGRAM, CONSERVATION INTERNATIONAL–CABS, WORLD WILDLIFE FUND–U.S. AND ENVIRONMENT CANADA–WILDSPACE; AMPHIBIAN DATA FROM *GLOBAL AMPHIBIAN ASSESSMENT*, BY IUCN, CONSERVATION INTERNATIONAL AND NATURESERVE, 2004 (WWW.GLOBALAMPHIBIANS.ORG), AS OF APRIL 1, 2005; HEIDI AND HANS-JUERGEN KOCH *Minden Pictures* (*glass frog*)

SAVING SPECIAL PLACES

The world's three remaining tropical forests and 25 "hot spots" (*indicated on map*) harbor most of the world's species of plants and animals. Norman Myers of Duke University defines hot spots as areas that have large numbers of endemic plants and that have lost at least 70 percent of their vegetative cover. Protecting these places and the remaining tropical wilderness forests would support the most species at the least cost.


Red-knobbed hornbill, Sulawesi
Monster flower, Borneo
Moth feeding on orchid, Madagascar
Caucasus
500,000 km^2
10% (28%)
1,600
South-Central China
800,000 km^2
8% (26%)
3,500
New Guinean Forest
Philippines
300,800 km^2
3% (43%)
5,832
New Caledonia
18,600 km^2
28% (10%)
2,551
Western Ghats/Sri Lanka
182,500 km^2
7% (100%)
2,180
Indo-Burma
2,060,000 km^2
5% (100%)
7,000
Eastern Arc and Coastal Forests of Tanzania and Kenya
30,000 km^2
7% (100%)
1,500
New Zealand
270,500 km^2
22% (88%)
1,865
Wallacea
347,000 km^2
15% (39%)
1,500
Sundaland
1,600,000 km^2
8% (72%)
15,000
Madagascar (including Mauritius, Reunion, Seychelles and Comoros)
594,150 km^2
10% (20%)
9,704
Southwest Australia
309,850 km^2
11% (100%)
4,331



BRAZILIAN STATE of Rio de Janeiro (*in red below and shown on elevation map at right*) has one of the largest concentrations of species at risk in the world. The cattle pasture that the authors are visiting at the start of the article lies in a patch of lowland forest there. Most of the state's threatened endemic bird species live in such fragments. Reconnecting these areas to the higher elevation forests is the major conservation priority. (Gray areas no longer have forest.)

countries, but not much. The damage extensive logging causes to natural areas—and to the people who live there—can be considerable. What would it cost for conservation groups to buy out the leases? Based on actual purchases, the cost would be $5 billion for the roughly five million square kilometers of wet forests that are still wilderness. That does not seem to be an impossible task given how much private money flows into international conservation organizations.

Certainly there are many other challenges in helping forest-rich nations develop alternatives to logging, not least of which is that the value of forests to loggers might increase as more were protected. Illegal logging is widespread: What guarantees are there that the forests will remain protected? Indonesia, for example, has the second largest forest reserves. It ranks near the bottom of the league in international evaluations of freedom from corruption and has a bad record of violating the rights of its forests' indigenous peoples.

Displaced poor people clear the largest fraction of the shrinking tropical forests. Some were coerced to leave their farms elsewhere; others were encouraged by governments seeking a solution to urban poverty. Practically or ethically, we cannot simply admonish them to not clear forest. If we, the rich, value these forests as forests and not as pastures for scrawny cattle, then we must find ways to reward financially the countries that keep forests intact. Vitally, we must find ways to ensure that those rewards go to the people at the forests' edges who make the daily decisions about the forests' fate. Like politics, conservation is local.

Hot spots present challenges different from those of the sparsely populated wilderness forests. Hot spots are heavily populated, and land prices are much higher. Is it practical to protect what remains of them? Yes, but we have to be smart.

Consider Brazil's remaining coastal forests. Working with Alves and her colleagues, we have reached a joint solution that combines knowledge of species' distributions with remotely sensed maps of remaining forest cover and elevation [*see illustration above*]. The higher-elevation forests survive in large, continuous blocks. Their physical inaccessibility protects them, and they have few species at risk. Our greater concern is the lowland forests. They have the highest numbers of vulnerable species and are chopped up into small patches. Fragmentation is a problem, because the vulnerable populations of animals and plants in each piece may dwindle to extinction in the absence of occasional immigrants. Fragmentation also prevents species from dispersing to cooler habitats upslope, as they may need to do because of global warming.

Restoring forests to the gaps between lowland forests—such as the cattle pasture—is effective and, because of the small areas involved, relatively cheap. Crucially, we work with local scientists and at the behest of local organizations. Biodiverse countries are all desperately short of personnel to tailor their problems of species loss to the hugely variable local economies, political systems, and religious and cultural beliefs. One cannot expect natural areas to remain intact unless well-trained, local

THE AUTHORS

STUART L. PIMM and CLINTON JENKINS

PIMM and *JENKINS* work at the Nicholas School of the Environment and Earth Sciences at Duke University. They are conservation ecologists who seek to document past and probable future extinctions to find effective methods to prevent the latter. Jenkins specializes in using GIS (geographic information systems) and remote-sensing technology to map priorities for conservation actions.

DATA SOURCES ON PAGES 70 AND 71: TROPICAL FOREST DATA FROM *THE GLOBAL 200: PRIORITY ECOREGIONS FOR GLOBAL CONSERVATION*, BY D. M. OLSON AND E. DINERSTEIN IN *ANNALS OF THE MISSOURI BOTANICAL GARDEN*, VOL. 89, NO. 2, PAGES 99–125, 2002; CURRENT FOREST COVER DATA FROM *THE GLOBAL LAND COVER MAP FOR THE YEAR 2000*, GLC2000 DATABASE, EUROPEAN COMMISSION JOINT RESEARCH CENTER, 2002 (WWW-GVM.JRC.IT/GLC2000); HOT-SPOT DATA FROM NORMAN MYERS *Duke University*; THIS PAGE: DATA ABOUT THREATENED BIRDS FROM *ECOLOGICAL AND DISTRIBUTIONAL DATABASES*, BY T. A. PARKER III, D. F. STOTZ AND J. W. FITZPATRICK IN *NEOTROPICAL BIRDS: ECOLOGY AND CONSERVATION*, BY D. F. STOTZ, J. W. FITZPATRICK, T. A. PARKER III AND D. K. MOSKOVITS, UNIVERSITY OF CHICAGO PRESS, 1996

conservation professionals are on hand to resolve creatively the inevitable disputes over using their country's resources.

Getting the Incentives Right

WHY SHOULDN'T BRAZIL clear the forests of the Amazon to reap the benefits that the U.S. once did by clearing its forests? (Brazil has an ambitious plan, Avança Brasil, to do just that.) To begin with, the analogy between the two nations is flawed. The soils underlying many humid forests, unlike those in temperate forests, are extremely poor. Globally, some seven million square kilometers of wet tropical forest have been cleared, about half its original extent. Because of the poor soil and inefficient agricultural practices, only two million square kilometers have become cropland. The remainder is often unusable, infested with unpalatable weeds and able to support few cattle or goats. The tracts of abandoned, once forested land provide ample refutation to those who think forest clearing will inevitably drive an economic boom.

Seven million km^2 of humid tropical forest have been cleared, about half its original extent, but only two million km^2 have become productive cropland.

I'iwi and Ohia flower, Hawaii

Second, a country that argues that it must destroy its natural resources to develop often incurs untoward consequences from that decision. The U.S. offers a case in point. It has harmed most of its rivers by damming and channeling them. The tremendous cost of these projects to the taxpayer has often been financially disastrous. For example, a monumental series of dikes and levees massively damage the Everglades of southern Florida, mostly to facilitate growing sugarcane on reclaimed wetland. To maintain homegrown production, Americans pay approximately $1 billion a year more for sugar than they would on world markets. The costs to the taxpayer of building and maintaining those dikes and levees, of cleaning up the pollution and of subsidizing local property taxes are additional. So, too, is a $10-billion restoration plan for the Everglades that funds future water deliveries to southern Florida but provides little or no benefits to the Everglades in its first quarter of a century of operation.

Fisheries offer even more examples, because, as a result of general government subsidies, the world fish catch is worth less than it costs to acquire. In their book *Perverse Subsidies,* Myers and Jennifer Kent quote an estimated market price of $70 billion in 1989. The cost of catching the fish was $124 billion, and even this number overlooks additional subsidies from provincial or state governments.

The other side of this coin is that nature provides crucial but undervalued services. The recently released Millennium Ecosystem Assessment report has a long list: food, freshwater, fuelwood, medicinal plants, wild varieties of crop plants, flood prevention and climate regulation, among others. All these values are in addition to recreational, aesthetic and spiritual benefits that a country should consider as it decides whether chopping down a forest is really worth it.

One way that rich nations could support the decision to preserve a forest would be to extend the Kyoto carbon-trading system to developing nations [see "How Shall We Set Priorities?" by W. Wayt Gibbs, on page 108]. According to the Intergovernmental Panel on Climate Change, alterations in land use, of which forest clearing is the most important, produce a quarter of global carbon dioxide emissions. An international market in carbon could create incentives for forest-rich countries to keep their forests, rather than converting them to cattle pastures.

Another international incentive is ecotourism. Tropical forests, coral reefs and wetlands—indeed the entire range of places where vulnerable species live—are fascinating for exactly that reason. The ecotourist often ventures to places far from a nation's capital and what largesse its leaders can distribute. In the remote village in northwestern Madagascar where our group works, the average income is less than $1 a day. The money tourists pay to visit the nearby national park, to eat at a local restaurant and to stay at a campsite is small by international accounting standards, but locally it is a powerful reason not to burn the forest and the lemurs that live in it.

Protecting biodiversity—whether in remote forests or in the concentrated hot spots on land and in the oceans—is achievable. Many of the necessary measures are inexpensive, and many supply local economic benefits. Whether we effect such measures is up to this generation. By the time the next generation has the opportunity to decide, it may be too late. SA

MORE TO EXPLORE

Biodiversity Hotspots for Conservation Priorities. N. Myers, R. A. Mittermeier, C. G. Mittermeier, G.A.B. da Fonseca and J. Kent in *Nature,* Vol. 403, pages 853–858; February 24, 2000.

Can We Defy Nature's End? S. L. Pimm et al. in *Science,* Vol. 293, pages 2207–2208; September 21, 2001.

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Ecosystems and Human Well-being: Synthesis Report (Millennium Ecosystem Assessment). Island Press, 2005.

PHOTOGRAPHS ON PAGES 70 AND 71: FRANS LANTING *Minden Pictures* (*chameleon, monster flower and maned wolf*); W. WAYT THOMAS *New York Botanical Garden* (*N. corticola*); MARK JONES *Minden Pictures* (*hornbill*); MITSUHIKO IMAMORI *Minden Pictures* (*moth*); THIS PAGE: FRANS LANTING *Minden Pictures*

MORE PROFIT WITH LESS CARBON

BY AMORY B. LOVINS

Focusing on energy efficiency will do more than protect Earth's climate—it will make businesses and consumers richer

A basic misunderstanding skews the entire climate debate. Experts on both sides claim that protecting Earth's climate will force a trade-off between the environment and the economy. According to these experts, burning less fossil fuel to slow or prevent global warming will increase the cost of meeting society's needs for energy services, which include everything from speedy transportation to hot showers. Environmentalists say the cost would be modestly higher but worth it; skeptics, including top U.S. government officials, warn that the extra expense would be prohibitive. Yet both sides are wrong. If properly done, climate protection would actually *reduce* costs, not raise them. Using energy more efficiently offers an economic bonanza—not because of the benefits of stopping global warming but because saving fossil fuel is a lot cheaper than buying it.

The world abounds with proven ways to use energy more productively, and smart businesses are leaping to exploit them. Over the past decade, chemical manufacturer DuPont has boosted production nearly 30 percent but cut energy use 7 percent and greenhouse gas emissions 72 percent (measured in terms of their carbon dioxide equivalent), saving more than $2 billion so far. Five other major firms—IBM, British Telecom, Alcan, NorskeCanada and Bayer—have collectively saved at least another $2 billion since the early 1990s by reducing their carbon emissions more than 60 percent. In 2001 oil giant BP met its 2010 goal of reducing carbon dioxide emissions 10 percent below the company's 1990 level, thereby cutting its energy bills $650 million over 10 years. And just this past May, General Electric vowed to raise its energy efficiency 30 percent by 2012 to enhance the company's shareholder value. These sharp-penciled firms, and dozens like them, know that energy efficiency improves the bottom line and yields even more valuable side benefits: higher quality and reliability in energy-efficient factories, 6 to 16 percent higher labor productivity in efficient offices, and 40 percent higher sales in stores skillfully designed to be illuminated primarily by daylight.

The U.S. now uses 47 percent less energy per dollar of economic output than it did 30 years ago, lowering costs

BURNING FOSSIL FUELS not only contributes to global warming—it wastes money. Improving the energy efficiency of factories, buildings, vehicles and consumer products would swiftly reduce the consumption of coal and oil, curbing the damage to Earth's climate while saving immense amounts of money for businesses and households.

CARY WOLINSKY (*photography*); JEN CHRISTIANSEN (*photoillustration*)

by $1 billion a day. These savings act like a huge universal tax cut that also reduces the federal deficit. Far from dampening global development, lower energy bills accelerate it. And there is plenty more value to capture at every stage of energy production, distribution and consumption. Converting coal at the power plant into incandescent light in your house is only 3 percent efficient. Most of the waste heat discarded at U.S. power stations—which amounts to 20 percent more energy than Japan uses for everything—could be lucratively recycled. About 5 percent of household electricity in the U.S. is lost to energizing computers, televisions and other appliances that are turned off. (The electricity wasted by poorly designed standby circuitry is equivalent to the output of more than a dozen 1,000-megawatt power stations running full-tilt.) In all, preventable energy waste costs Americans hundreds of billions of dollars and the global economy more than $1 trillion a year, destabilizing the climate while producing no value.

CROSSROADS FOR
ENERGY

THE PROBLEM

- The energy sector of the global economy is woefully inefficient. Power plants and buildings waste huge amounts of heat, cars and trucks dissipate most of their fuel energy, and consumer appliances waste much of their power (and often siphon electricity even when they are turned off).
- If nothing is done, the use of oil and coal will continue to climb, draining hundreds of billions of dollars a year from the economy as well as worsening the climate, pollution and oil-security problems.

THE PLAN

- Improving end-use efficiency is the fastest and most lucrative way to save energy. Many energy-efficient products cost no more than inefficient ones. Homes and factories that use less power can be cheaper to build than conventional structures. Reducing the weight of vehicles can double their fuel economy without compromising safety or raising sticker prices.
- With the help of efficiency improvements and competitive renewable energy sources, the U.S. can phase out oil use by 2050. Profit-seeking businesses can lead the way.


Rooftop solar array

If energy efficiency has so much potential, why isn't everyone pursuing it? One obstacle is that many people have confused efficiency (doing more with less) with curtailment, discomfort or privation (doing less, worse or without). Another obstacle is that energy users do not recognize how much they can benefit from improving efficiency, because saved energy comes in millions of invisibly small pieces, not in obvious big chunks. Most people lack the time and attention to learn about modern efficiency techniques, which evolve so quickly that even experts cannot keep up. Moreover, taxpayer-funded subsidies have made energy seem cheap. Although the U.S. government has declared that bolstering efficiency is a priority, this commitment is mostly rhetorical. And scores of ingrained rules and habits block efficiency efforts or actually reward waste. Yet relatively simple changes can turn all these obstacles into business opportunities.

Enhancing efficiency is the most vital step toward creating a climate-safe energy system, but switching to fuels that emit less carbon will also play an important role. The world economy is already decarbonizing: over the past two centuries, carbon-rich fuels such as coal have given way to fuels with less carbon (oil and natural gas) or with none (renewable sources such as solar and wind power). Today less than one third of the fossil-fuel atoms burned are carbon; the rest are climate-safe hydrogen. This decarbonization trend is reinforced by greater efficiencies in converting, distributing and using energy; for example, combining the production of heat and electricity can extract twice as much useful work from each ton of carbon emitted into the atmosphere. Together these advances could dramatically reduce total carbon emissions by 2050 even as the global economy expands. This article focuses on the biggest prize: wringing more work from each unit of energy delivered to businesses and consumers. Increasing end-use efficiency can yield huge savings in fuel, pollution and capital costs because large amounts of energy are lost at every stage of the journey from production sites to delivered services [*see box on opposite page*]. So even small reductions in the power used at the downstream end of the chain can enormously lower the required input at the upstream end.

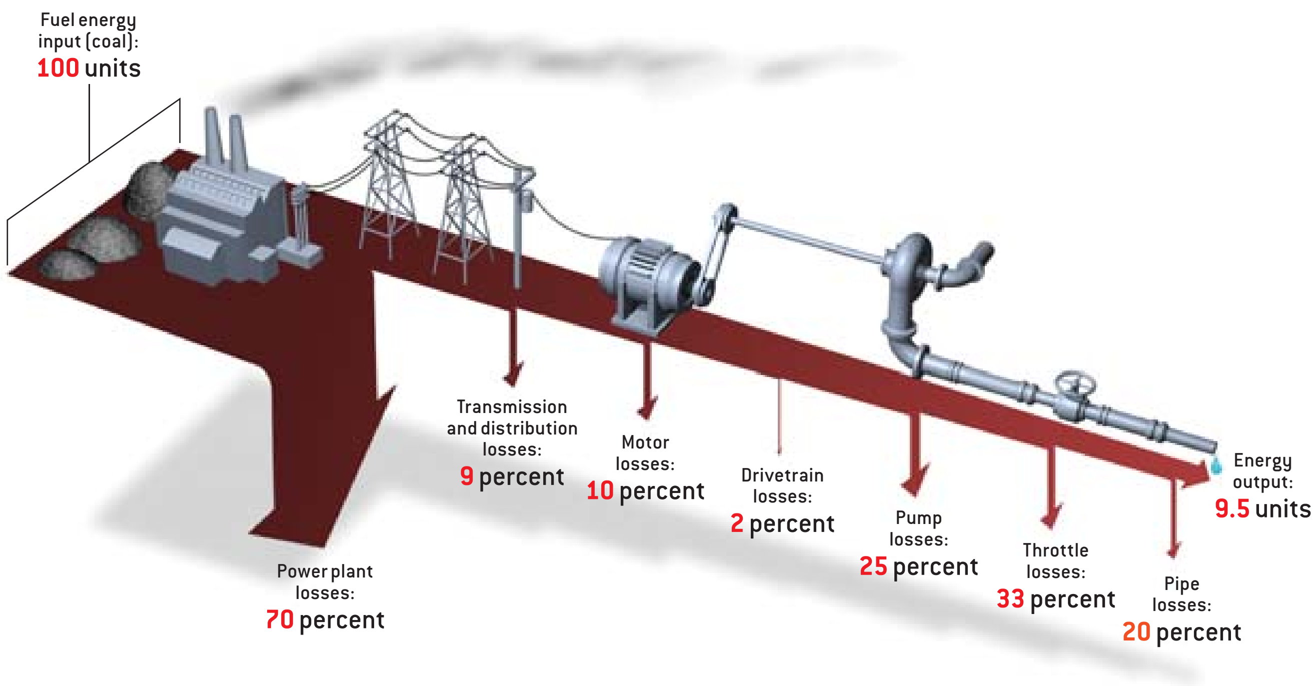
The Efficiency Revolution

MANY ENERGY-EFFICIENT PRODUCTS, once costly and exotic, are now inexpensive and commonplace. Electronic speed controls, for example, are mass-produced so cheaply that some suppliers give them away as a free bonus with each motor. Compact fluorescent lamps cost more than $20 two decades ago but only $2 to $5 today; they use 75 to 80 percent less electricity than incandescent bulbs and last 10 to 13 times longer. Window coatings that transmit light but reflect heat cost one fourth of what they did five years ago. Indeed, for many kinds of equipment in competitive markets—motors, industrial pumps, televisions, refrigerators—some highly energy-efficient models cost no more than inefficient ones. Yet far more important than all these better and cheaper technologies is a hidden revolution in the design that combines and applies them.

S. STRONG *Solar Design Associates, Inc.*

COMPOUNDING LOSSES

From the power plant to an industrial pipe, inefficiencies along the way whittle the energy input of the fuel—set at 100 arbitrary units in this example—by more than 90 percent, leaving only 9.5 units of energy delivered as fluid flow through the pipe. But small increases in end-use efficiency can reverse these compounding losses. For instance, saving one unit of output energy by reducing friction inside the pipe will cut the needed fuel input by 10 units, slashing cost and pollution at the power plant while allowing the use of smaller, cheaper pumps and motors.



For instance, how much thermal insulation is appropriate for a house in a cold climate? Most engineers would stop adding insulation when the expense of putting in more material rises above the savings over time from lower heating bills. But this comparison omits the capital cost of the heating system—the furnace, pipes, pumps, fans and so on—which may not be necessary at all if the insulation is good enough. Consider my own house, built in 1984 in Snowmass, Colo., where winter temperatures can dip to –44 degrees Celsius and frost can occur any day of the year. The house has no conventional heating system; instead its roof is insulated with 20 to 30 centimeters of polyurethane foam, and its 40-centimeter-thick masonry walls sandwich another 10 centimeters of the material. The double-pane windows combine two or three transparent heat-reflecting films with insulating krypton gas, so that they block heat as well as eight to 14 panes of glass. These features, along with heat recovery from the ventilated air, cut the house's heat losses to only about 1 percent more than the heat gained from sunlight, appliances and people inside the structure. I can offset this tiny loss by playing with my dog (who generates about 50 watts of heat, adjustable to 100 watts if you throw a ball to her) or by burning obsolete energy studies in a small woodstove on the coldest nights.

Eliminating the need for a heating system reduced construction costs by $1,100 (in 1983 dollars). I then reinvested this money, plus another $4,800, into equipment that saved half the water, 99 percent of the water-heating energy and 90 percent of the household electricity. The 4,000-square-foot structure—which also houses the original headquarters of Rocky Mountain Institute (RMI), the nonprofit group I cofounded in 1982—consumes barely more electricity than a single 100-watt lightbulb. (This amount excludes the power used by the institute's office equipment.) Solar cells generate five to six times that much electricity, which I sell back to the utility. Together all the efficiency investments repaid their cost in 10 months with 1983 technologies; today's are better and cheaper.

In the 1990s Pacific Gas & Electric undertook an experiment called ACT^2 that applied smart design in seven new and old buildings to demonstrate that large efficiency improvements can be cheaper than small ones. For example, the company built a new suburban tract house in Davis, Calif., that could stay cool in the summer without air-conditioning. PG&E estimated that such a design, if widely adopted, would cost about $1,800 less to build and $1,600 less to maintain over its lifetime than a conventional home of the same size. Similarly, in 1996 Thai architect Soontorn Boonyatikarn built a house near steamy Bangkok that required only one-seventh

DON FOLEY

the air-conditioning capacity usually installed in a structure of that size; the savings in equipment costs paid for the insulating roof, walls and windows that keep the house cool [*see box on opposite page*]. In all these cases, the design approach was the same: optimize the whole building for multiple benefits rather than use isolated components for single benefits.

Such whole-system engineering can also be applied to office buildings and factories. The designers of a carpet factory built in Shanghai in 1997 cut the pumping power required for a heat-circulating loop by 92 percent through two simple changes. The first change was to install fat pipes rather than thin ones, which greatly reduced friction and hence allowed the system to use smaller pumps and motors. The second innovation was to lay out the pipes before positioning the equipment they connect. As a result, the fluid moved through short, straight pipes instead of tracing circuitous paths, further reducing friction and capital costs.

This isn't rocket science; it's just good Victorian engineering rediscovered. And it is widely applicable. A practice team at RMI has recently developed new-construction designs offering energy savings of 89 percent for a data center, about 75 percent for a chemical plant, 70 to 90 percent for a supermarket and about 50 percent for a luxury yacht, all with capital costs lower than those of conventional designs. The team has also proposed retrofits for existing oil refineries, mines and microchip factories that would reduce energy use by 40 to 60 percent, repaying their cost in just a few years.

Vehicles of Opportunity

TRANSPORTATION CONSUMES 70 percent of U.S. oil and generates a third of the nation's carbon emissions. It is widely considered the most intractable part of the climate problem, especially as hundreds of millions of people in China and India buy automobiles. Yet transportation offers enormous efficiency opportunities. *Winning the Oil Endgame,* a 2004 analysis written by my team at RMI and co-sponsored by the Pentagon, found that artfully combining lightweight materials with innovations in propulsion and aerodynamics could cut oil use by cars, trucks and planes by two thirds without compromising comfort, safety, performance or affordability.

Despite 119 years of refinement, the modern car remains astonishingly inefficient. Only 13 percent of its fuel energy even reaches the wheels—the other 87 percent is either dissipated as heat and noise in the engine and drivetrain or lost to idling and accessories such as air conditioners. Of the energy delivered to the wheels, more than half heats the tires, road and air. Just 6 percent of the fuel energy actually accelerates the car (and all this energy converts to brake heating when you stop). And, because 95 percent of the accelerated mass is the car itself, less than 1 percent of the fuel ends up moving the driver.

Yet the solution is obvious from the physics: greatly reduce the car's weight, which causes three fourths of the energy losses at the wheels. And every unit of energy saved at the wheels by lowering weight (or cutting drag) will save an additional seven units of energy now lost en route to the wheels. Concerns about cost and safety have long discouraged attempts to make lighter cars, but modern light-but-strong materials—new metal alloys and advanced polymer composites—can slash a car's mass without sacrificing crashworthiness. For example, carbon-fiber composites can absorb six to 12 times as much crash energy per kilogram as steel does, more than offsetting the composite car's weight disadvantage if it hits a steel vehicle that is twice as heavy. With such novel materials, cars can be big, comfortable and protective without being heavy, inefficient and hostile, saving both oil *and* lives. As Henry Ford said, you don't need weight for strength; if you did, your bicycle helmet would be made of steel, not carbon fiber.

Advanced manufacturing techniques developed in the past two years could make carbon-composite car bodies competitive with steel ones. A lighter body would allow automakers to use smaller (and less expensive) engines. And because the assembly of carbon-composite cars does not require body or paint shops, the factories would be smaller and cost 40 percent less to build than conventional auto plants. These savings would offset the higher cost of the carbon-composite materials. In all, the introduction of ultralight bodies could nearly double the fuel efficiency of today's hybrid-electric vehicles—which are already twice as efficient as conventional cars—without raising their sticker prices. If composites prove unready, new ultralight steels offer a reliable backstop. The competitive marketplace will sort out the winning materials, but, either way, superefficient ultralight vehicles will start pulling

Using energy more efficiently offers an economic bonanza—not because of the benefits of stopping global warming but because saving fossil fuel is a lot cheaper than buying it.

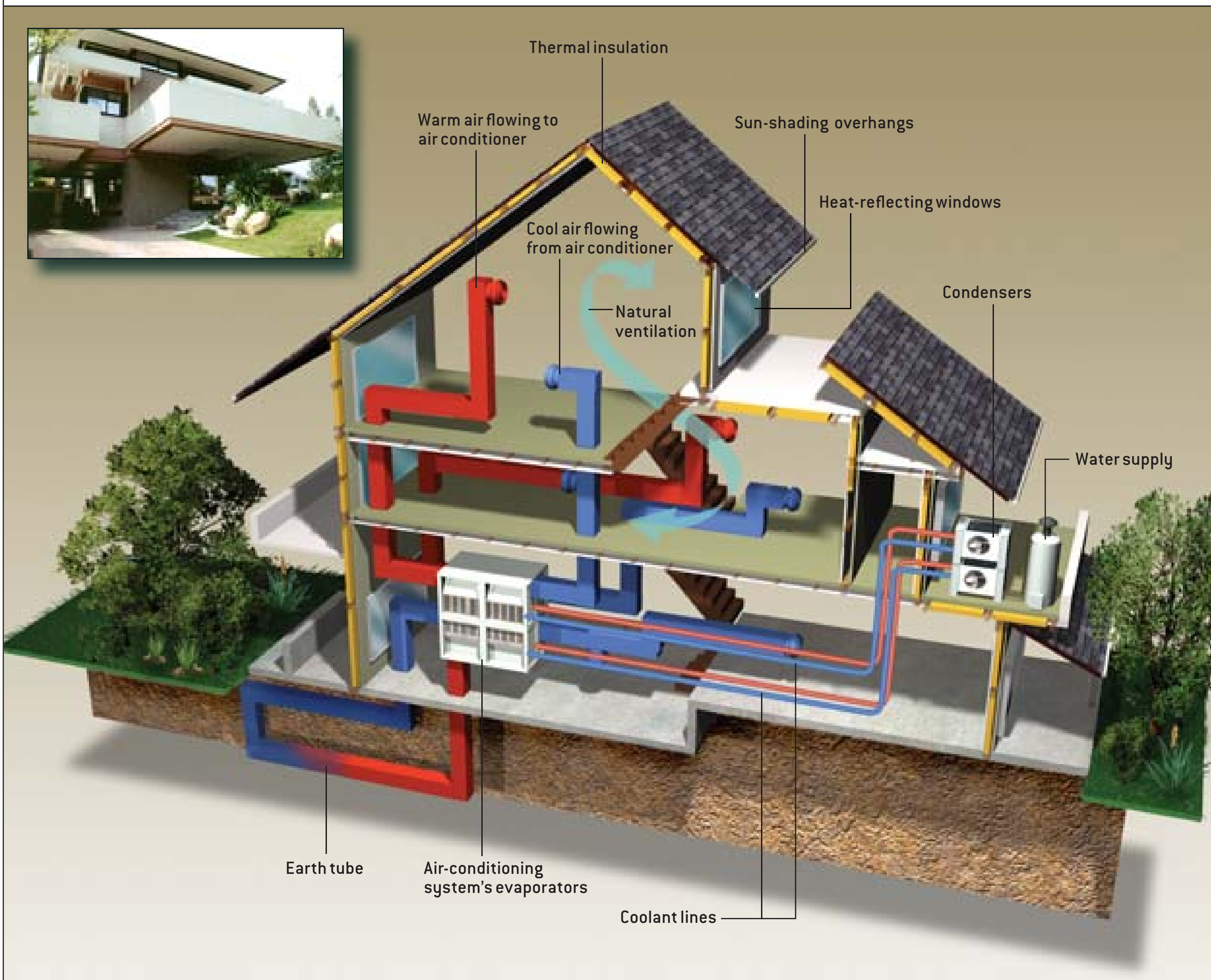
THE AUTHOR

AMORY B. LOVINS

LOVINS is co-founder and chief executive of Rocky Mountain Institute, an entrepreneurial nonprofit organization based in Snowmass, Colo., and chairman of Fiberforge, an engineering firm in Glenwood Springs, Colo. A physicist, Lovins has consulted for industry and governments worldwide for more than 30 years, chiefly on energy and its links with the environment, development and security. He has published 29 books and hundreds of papers on these subjects and has received a MacArthur Fellowship and many other awards for his work.

SAVING ENERGY BY DESIGN

How can you keep cool in tropical Thailand while minimizing power usage? Architect Soontorn Boonyatikarn of Chulalongkorn University used overhangs and balconies to shade his 350-square-meter home in Pathumthani, near Bangkok. Insulation, an airtight shell and infrared-reflecting windows keep heat out of the house while letting in plenty of daylight. An open floor plan and central stairwell promote ventilation, and indoor air is cooled as it flows through an underground tube. As a result, the house needs just one seventh of the typical air-conditioning capacity for a structure of its size. To further reduce energy bills, the air-conditioning system's condensers heat the house's water.



DON FOLEY (*schematic*); SOONTORN BOONYATIKARN *Chulalongkorn University* (*photograph*)

away from the automotive pack within the next decade.

What is more, ultralight cars could greatly accelerate the transition to hydrogen fuel-cell cars that use no oil at all [see "On the Road to Fuel-Cell Cars," by Steven Ashley; SCIENTIFIC AMERICAN, March]. A midsize SUV whose halved weight and drag cut its needed power to the wheels by two thirds would have a fuel economy equivalent to 114 miles per gallon and thus require only a 35-kilowatt fuel cell—one third the usual size and hence much easier to manufacture affordably [*see box on page 81*]. And because the vehicle would need to carry only one third as much hydrogen, it would not require any new storage technologies; compact, safe, off-the-shelf carbon-fiber tanks could hold enough hydrogen to propel the SUV for 530 kilometers. Thus, the first automaker to go ultralight will win the race to fuel cells, giving the whole industry a strong incentive to become as boldly innovative in materials and manufacturing as a few companies now are in propulsion.

RMI's analysis shows that full adoption of efficient vehicles, buildings and industries could shrink projected U.S. oil use in 2025—28 million barrels a day—by more than half, lowering consumption to pre-1970 levels. In a realistic scenario, only about half of these savings could actually be captured by 2025 because many older, less efficient cars and trucks would remain on the road (vehicle stocks turn over slowly). Before 2050, though, U.S. oil consumption could be phased out altogether by doubling the efficiency of oil use and substituting alternative fuel supplies [*see illustration on page 83*]. Businesses can profit greatly by making the transition, because saving each barrel of oil through efficiency improvements costs only $12, less than one fifth of what petroleum sells for today. And two kinds of alternative fuel supplies could compete robustly with oil even if it sold for less than half the current price. The first is ethanol made from woody, weedy plants such as switchgrass and poplar. Corn is currently the main U.S. source of ethanol, which is blended with gasoline, but the woody plants yield twice as much ethanol per ton as corn does and with lower capital investment and far less energy input.

The second alternative is replacing oil with lower-carbon natural gas, which would become cheaper and more abundant as efficiency gains reduce the demand for electricity at peak periods. At those times, gas-fired turbines generate power so wastefully that saving 1 percent of electricity would cut U.S. natural gas consumption by 2 percent and its price by 3 or 4 percent. Gas saved in this way and in other uses could then replace oil either directly or, even more profitably and efficiently, by converting it to hydrogen.

The benefits of phasing out oil would go far beyond the estimated $70 billion saved every year. The transition would lower U.S. carbon emissions by 26 percent and eliminate all the social and political costs of getting and burning petroleum—military conflict, price volatility, fiscal and diplomatic distortions, pollution and so on. If the country becomes oil-free, then petroleum will no longer be worth fighting over. The Pentagon would also reap immediate rewards from raising energy efficiency because it badly needs to reduce the costs and risks of supplying fuel to its troops. Just as the U.S. Department of Defense's research efforts transformed civilian industry by creating the Internet and the Global Positioning System, it should now spearhead the development of advanced ultralight materials.

The switch to an oil-free economy would happen even faster than RMI projected if policymakers stopped encouraging the perverse development patterns that make people drive so much. If federal, state and local governments did not mandate and subsidize suburban sprawl, more of us could live in neighborhoods where almost everything we want is within a five-minute walk. Besides saving fuel, this New Urbanist design builds stronger communities, earns more money for developers and is much less disruptive than other methods of limiting vehicle traffic (such as the draconian fuel and car taxes that Singapore uses to avoid Bangkok-like traffic jams).

ADDICTED TO OIL

28 million
Barrels of oil that will be consumed each day in the U.S. by 2025 if current trends continue

13 percent
The proportion of a car's fuel energy that reaches its wheels

$70 billion
Annual savings (by 2025) from improving the efficiency of oil use and finding substitutes for oil

Renewable Energy

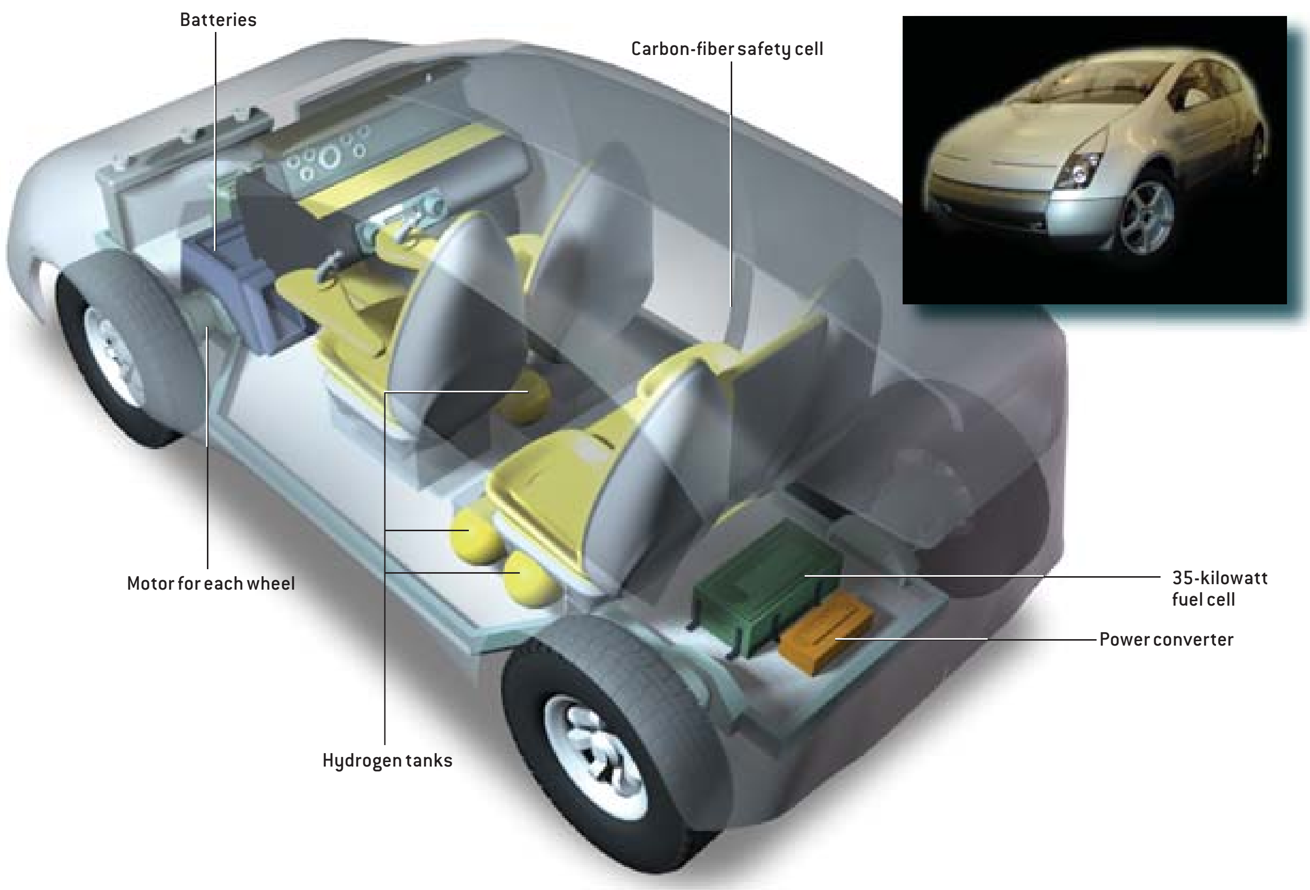
EFFICIENCY IMPROVEMENTS that can save most of our electricity also cost less than what the utilities now pay for coal, which generates half of U.S. power and 38 percent of its fossil-fuel carbon emissions. Furthermore, in recent years alternatives to coal-fired power plants—including renewable sources such as wind and solar power, as well as decentralized cogeneration plants that produce electricity and heat together in buildings and factories—have begun to hit their stride. Worldwide the collective generating capacity of these sources is already greater than that of nuclear power and growing six times as fast [*see illustration on page 82*]. This trend is all the more impressive because decentralized generators face many obstacles to fair competition and usually get much lower subsidies than centralized coal-fired or nuclear plants.

Wind power is perhaps the greatest success story. Mass production and improved engineering have made modern wind turbines big (generating two to five megawatts each), extremely reliable and environmentally quite benign. Denmark already gets a fifth of its electricity from wind, Germany a tenth. Germany and Spain are each adding more than 2,000 megawatts of wind power each year, and Europe aims to get 22 percent of its electricity and 12 percent of its total energy from renewables by 2010. In contrast, global nuclear generating capacity is expected to remain flat, then decline.

The most common criticism of wind power—that it produces electricity too intermittently—has not turned out to be a serious drawback. In parts of Europe that get all their power from wind on some days, utilities have overcome the problem by diversifying the locations of their wind turbines, incorporating wind forecasts into their generating plans and integrating wind power with hydroelectricity and other energy sources. Wind and solar power work particularly well together, partly because the conditions that are bad for wind (calm, sunny weather) are good for solar, and vice versa. In fact, when properly combined, wind and solar facilities are more reliable than conventional power stations—they come in smaller modules (wind turbines, solar cells) that are less likely to fail all at once, their costs do not swing wildly with the prices of fossil fuels, and terrorists are much more likely to attack a nuclear

A LEAN, MEAN DRIVING MACHINE

Ultralight cars can be fast, roomy, safe and efficient. A concept five-seat midsize SUV called the Revolution, designed in 2000, weighs only 857 kilograms—less than half the weight of a comparable conventional car—yet its carbon-fiber safety cell would protect passengers from high-speed collisions with much heavier vehicles. A 35-kilowatt fuel cell could propel the car for 530 kilometers on 3.4 kilograms of hydrogen stored in its tanks. And the Revolution could accelerate to 100 kilometers per hour in 8.3 seconds.



reactor or an oil terminal than a wind farm or a solar array.

Most important, renewable power now has advantageous economics. In 2003 U.S. wind energy sold for as little as 2.9 cents a kilowatt-hour. The federal government subsidizes wind power with a production tax credit, but even without that subsidy, the price—about 4.6 cents per kilowatt-hour—is still cheaper than subsidized power from new coal or nuclear plants. (Wind power's subsidy is a temporary one that Congress has repeatedly allowed to expire; in contrast, the subsidies for the fossil-fuel and nuclear industries are larger and permanent.) Wind power is also abundant: wind farms occupying just a few percent of the available land in the Dakotas could cost-effectively meet all of America's electricity needs. Although solar cells currently cost more per kilowatt-hour than wind turbines do, they can still be profitable if integrated into buildings, saving the cost of roofing materials. Atop big, flat-roofed commercial buildings, solar cells can compete without subsidies if combined with efficient use that allows the building's owner to resell the surplus power when it is most plentiful and valuable—on sunny afternoons. Solar is also usually the cheapest way to get electricity to the two billion people, mostly in the developing world, who have no access to power lines. But even in rich countries, a house as efficient as mine can get all its electricity from just a few square meters of solar cells, and installing the array costs less than connecting to nearby utility lines.

Cheaper to Fix

INEXPENSIVE EFFICIENCY improvements and competitive renewable sources can reverse the terrible arithmetic of climate change, which accelerates exponentially as we burn fossil fuels ever faster. Efficiency can outpace economic growth if we pay attention: between 1977 and 1985, for example, U.S. gross domestic product (GDP) grew 27 percent, whereas oil use fell 17 percent. (Over the same period, oil imports dropped 50 percent, and Persian Gulf imports plummeted 87 percent.) The growth of renewables has routinely outpaced GDP; worldwide, solar and wind power are doubling every two and three years, respectively. If both efficiency and renewables grow faster than the economy, then carbon emissions will fall and global warming will slow—buying more time to develop even

DON FOLEY (*schematic*); HYPERCAR, INC. (*photograph*) better technologies for displacing the remaining fossil-fuel use, or to master and deploy ways to capture combustion carbon before it enters the air [see "Can We Bury Global Warming?" by Robert H. Socolow; Scientific American, July].

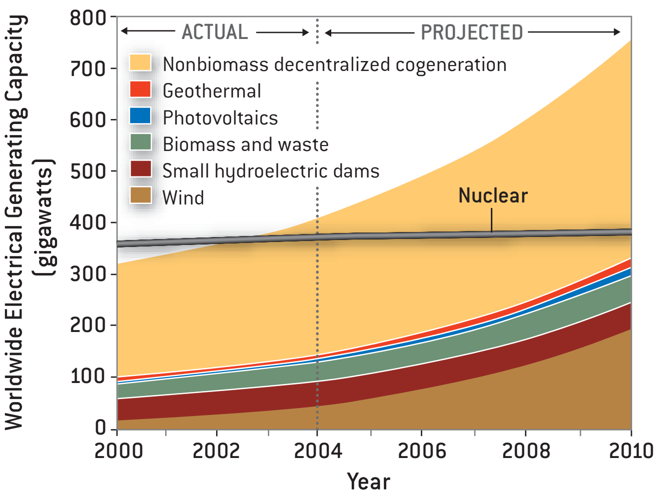
In contrast, nuclear power is a slower and much more expensive solution. Delivering a kilowatt-hour from a new nuclear plant costs at least three times as much as saving one through efficiency measures. Thus, every dollar spent on efficiency would displace at least three times as much coal as spending on nuclear power, and the efficiency improvements could go into effect much more quickly because it takes so long to build reactors. Diverting public and private investment from market winners to losers does not just distort markets and misallocate financial capital—it worsens the climate problem by buying a less effective solution.

The good news about global warming is that it is cheaper to fix than to ignore. Because saving energy is profitable, efficient use is gaining traction in the marketplace. U.S. Environmental Protection Agency economist Skip Laitner calculates that from 1996 to mid-2005 prudent choices by businesses and consumers, combined with the shift to a more information- and service-based economy, cut average U.S. energy use per dollar of GDP by 2.1 percent a year—nearly three times as fast as the rate for the preceding 10 years. This change met 78 percent of the rise in demand for energy services over the past decade (the remainder was met by increasing energy supply), and the U.S. achieved this progress without the help of any technological breakthroughs or new national policies. The climate problem was created by millions of bad decisions over decades, but climate stability can be restored by millions of sensible choices—buying a more efficient lamp or car, adding insulation or caulk to your home, repealing subsidies for waste and rewarding desired outcomes (for example, by paying architects and engineers for savings, not expenditures).

The proper role of government is to steer, not row, but for years officials have been steering our energy ship in the wrong direction. The current U.S. energy policy harms the economy and the climate by rejecting free-market principles and playing favorites with technologies. The best course is to allow every method of producing or saving energy to compete fairly, at honest prices, regardless of which kind of investment it is, what technology it uses, how big it is or who owns it. For example, few jurisdictions currently let decentralized power sources such as rooftop solar arrays "plug and play" on the electric grid, as modern technical standards safely permit. Although 31 U.S. states allow net metering—the utility buys your power at the same price it charges you—most artificially restrict or distort this competition. But the biggest single obstacle to electric and gas efficiency is that most countries, and all U.S. states except California and Oregon, reward distribution utilities for selling more energy and penalize them for cutting their customers' bills. Luckily, this problem is easy to fix: state regulators should align incentives by decoupling profits from energy sales, then letting utilities keep some of the savings from trimming energy bills.


Wind turbines in Germany

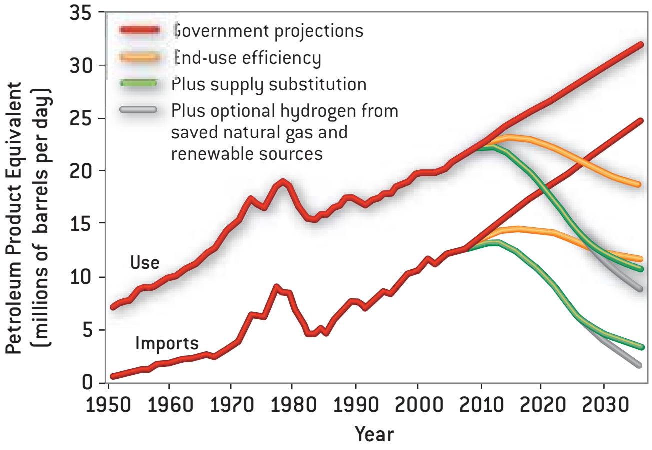
ELECTRICITY ALTERNATIVES



DECENTRALIZED SOURCES of electricity—cogeneration (the combined production of electricity and heat, typically from natural gas) and renewables (such as solar and wind power)—surpassed nuclear power in global generating capacity in 2002. The annual output of these low- and no-carbon sources will exceed that of nuclear power this year.

JEN CHRISTIANSEN; SOURCE: ROCKY MOUNTAIN INSTITUTE *(graph)*; ANDREAS RENTZ *Getty Images (photograph)*

AN OIL-FREE AMERICA



U.S. OIL CONSUMPTION AND IMPORTS can be profitably slashed by doubling the efficiency of vehicles, buildings and industries (*yellow lines in graph*). The U.S. can achieve further reductions by replacing oil with competitive substitutes such as advanced biofuels and saved natural gas (*green lines*) and with hydrogen fuel (*gray lines*).

JEN CHRISTIANSEN; SOURCE: RMI (*graph*); PROJECTIONS TO 2025 FROM U.S. ENERGY INFORMATION ADMINISTRATION; ESTIMATES AFTER 2025 FROM RMI

Superefficient vehicles have been slow to emerge from Detroit, where neither balance sheets nor leadership has supported visionary innovation. Also, the U.S. lightly taxes gasoline but heavily subsidizes its production, making it cheaper than bottled water. Increasing fuel taxes may not be the best solution, though; in Europe, stiff taxes—which raise many countries' gasoline prices to $4 or $5 a gallon—cut driving more than they make new cars efficient, because fuel costs are diluted by car owners' other expenses and are then steeply discounted (most car buyers count only the first few years' worth of fuel savings). Federal standards adopted in the 1970s helped to lift the fuel economy of new cars and light trucks from 16 miles per gallon in 1978 to 22 miles per gallon in 1987, but the average has slipped to 21 mpg since then. The government projects that the auto industry will spend the next 20 years getting its vehicles to be just 0.5 mile per gallon more efficient than they were in 1987. Furthermore, automakers loathe the standards as restrictions on choice and have become adept at gaming the system by selling more vehicles classified as light trucks, which are allowed to have lower fuel economy than cars. (The least efficient light trucks even get special subsidies.)

The most powerful policy response is "feebates"—charging fees on inefficient new cars and returning that revenue as rebates to buyers of efficient models. If done separately for each size class of vehicle, so there is no bias against bigger models, feebates would expand customer choice instead of restricting it. Feebates would also encourage innovation, save customers money and boost automakers' profits. Such policies, which can be implemented at the state level, could speed the adoption of advanced-technology cars, trucks and planes without mandates, taxes, subsidies or new national laws.

In Europe and Japan, the main obstacle to saving energy is the mistaken belief that their economies are already as efficient as they can get. These countries are up to twice as efficient as the U.S., but they still have a long way to go. The greatest opportunities, though, are in developing countries, which are on average three times less efficient than the U.S. Dreadfully wasteful motors, lighting ballasts and other devices are freely traded and widely bought in these nations. Their power sector currently devours one quarter of their development funds, diverting money from other vital projects. Industrial countries are partly responsible for this situation because many have exported inefficient vehicles and equipment to the developing world. Exporting inefficiency is both immoral and uneconomic; instead the richer nations should help developing countries build an energy-efficient infrastructure that would free up capital to address their other pressing needs. For example, manufacturing efficient lamps and windows takes 1,000 times less capital than building power plants and grids to do the same tasks, and the investment is recovered 10 times faster.

China and India have already discovered that their burgeoning economies cannot long compete if energy waste continues to squander their money, talent and public health. China is setting ambitious but achievable goals for shifting from coal-fired power to decentralized renewable energy and natural gas. (The Chinese have large supplies of gas and are expected to tap vast reserves in eastern Siberia.) Moreover, in 2004 China announced an energy strategy built around "leapfrog technologies" and rapid improvements in the efficiency of new buildings, factories and consumer products. China is also taking steps to control the explosive growth of its oil use; by 2008 it will be illegal to sell many inefficient U.S. cars there. If American automakers do not innovate quickly enough, in another decade you may well be driving a superefficient Chinese-made car. A million U.S. jobs hang in the balance.

Today's increasingly competitive global economy is stimulating an exciting new pattern of energy investment. If governments can remove institutional barriers and harness the dynamism of free enterprise, the markets will naturally favor choices that generate wealth, protect the climate and build real security by replacing fossil fuels with cheaper alternatives. This technology-driven convergence of business, environmental and security interests—creating abundance by design—holds out the promise of a fairer, richer and safer world. SA

MORE TO EXPLORE

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A complete list of references can be found online at **www.rmi.org/sitepages/pid173.php#C05-05**

THE BIG POTENTIAL OF SMALL FARMS

BY PAUL POLAK

With the help of affordable irrigation and access to markets, farmers in the developing world can grow more food and climb out of poverty

Peter Mwete, an angular Zimbabwean man in his 20s, was weeding his tiny vegetable plot in the settlement of Marimari when I met him in 2002. The 100-square-meter plot—about the size of a typical suburban backyard—was enclosed by a two-meter-high fence of stout poles cut from the bush and wired together to keep wild and domestic animals out. Peter lived with his father and a 19-year-old brother; his mother had died from AIDS, and his brother was also dying. To feed his family and earn a living with fewer hands to do the work, Peter had installed a low-cost, gravity-fed drip-irrigation kit provided by International Development Enterprises (IDE), the organization I started in 1981.

Peter's plot consisted of eight raised beds neatly planted with rape leaves, cabbage and corn. In the middle of each bed, a movable drip line delivered water from a 40-liter plastic tank placed atop a wooden stand. Because the drip system brought water directly to the roots, it was far more efficient than watering the plants by bucket. As a result, the small plot produced enough corn and vegetables to meet most of the family's needs, and Peter expected to earn at least $90—a substantial income for a farmer in Zimbabwe—from selling the surplus. He told me that in the following year he planned to double the size of his plot and triple his income by replacing some of the leafy vegetables with more valuable crops, such as tomatoes and Irish potatoes. He also planned to raise his plot's productivity by fertilizing it. Because he could not afford chemical fertilizers, he intended to dunk a burlap bag filled with cow manure into a water drum and apply this "manure tea" to the roots of his vegetables through the drip system.

Over the past three decades, I have spoken with thousands of small farmers in the developing world, and their stories are strikingly similar to Peter's. They can increase their earnings by as much as $500 a year by intensively farming 1,000-square-meter (quarter-acre) plots of fruits and vegetables, but they need better cultivation methods, affordable irrigation and access to markets for their crops. Their struggle is part of a global challenge: by 2050 the world's farmers must feed nine billion people—three billion more than the current population—without much expansion in the amount of land and water devoted to agriculture. Water, in particular, has emerged as the key to boosting farm production and easing poverty, because nearly 1,000 liters of water are needed to grow one kilogram of grain. We must store more water for irrigation and manage the supply we have more effectively.

Until now, governments and develop-

CHEAP IRRIGATION is the key to alleviating rural poverty and hunger in the developing world. In India's Maharashtra state, farmers employ an inexpensive, gravity-fed drip-irrigation system to deliver water to their sunflowers and vegetables.

ment agencies have tried to tackle the problem through large-scale projects: gigantic dams, sprawling irrigation canals and vast new fields of high-yield crops introduced during the Green Revolution, the famous campaign to increase grain harvests in developing nations. Traditional irrigation, however, has degraded the soil in many areas, and the reservoirs behind dams can quickly fill up with silt, reducing their storage capacity and depriving downstream farmers of fertile sediments. Furthermore, although the Green Revolution has greatly expanded worldwide farm production since 1950, poverty stubbornly persists in Africa, Asia and Latin America. Continued improvements in the productivity of large farms may play the main role in boosting food supply, but local efforts to provide cheap, individual irrigation systems to small farms may offer a better way to lift people out of poverty.

The Amazing Treadle Pump

OF ALL HUMAN ACTIVITIES, agriculture leaves the biggest footprint on Earth. About 70 percent of the water diverted for human use now goes to farming; another 19 percent goes to industry, 9 percent to homes and the rest to evaporation from reservoirs. One of the accomplishments of the Green Revolution was to enlarge the world's irrigated land, which grew from 100 million hectares in 1950 to 276 million today. (A hectare is equal to 10,000 square meters, or about 2.5 acres.) The resulting jump in harvests lowered the price of food, which contributed to reducing poverty among subsistence farmers and city dwellers. This effect, however, was offset by population growth. Between 1990 and 2001 the number of people worldwide living in extreme poverty—surviving on $1 a day or less—declined from 1.22 billion to 1.09 billion, but the number earning less than $2 a day rose from 2.65 billion to 2.74 billion. The trend was most dire in sub-Saharan Africa, where the population in extreme poverty leaped from 227 million to 313 million.

The Green Revolution was designed to increase the overall food supply, not to raise the incomes of the rural poor, so it should be no surprise that it did not eradicate poverty or hunger. India, for example, has been self-sufficient in food for 15 years, and its granaries are full, but more than 200 million Indians—one fifth of the country's population—are malnourished because they cannot afford the food they need and because the country's safety nets are deficient. In 2000 189 nations committed to the Millennium Development Goals, which called for cutting world poverty in half by 2015. With business as usual, however, we have little hope of achieving most of the Millennium goals, no matter how much money rich countries contribute to poor ones.

American agricultural researcher Norman Borlaug—who received the Nobel Peace Prize in 1970 for his contributions to the Green Revolution—was recently asked what wealthy countries should do to reduce hunger in the world. He said that they should send food during emergencies but that the long-range solution is revolutionizing agricultural production, especially among subsistence farmers in developing countries. This plan would not only increase food supply but also create jobs and generate new income from selling excess grain.

The supply-driven strategies of the Green Revolution, however, may not help subsistence farmers, who must play to their strengths to compete in the global marketplace. The average size of a family farm is less than four acres in India, 1.8 acres in Bangladesh and about half an acre in China. Combines and other modern farming tools are too expensive to be used on such small areas. An Indian farmer selling surplus wheat grown on his one-acre plot could not possibly compete with the highly efficient and subsidized Canadian wheat farms that typically stretch over thousands of acres. Instead subsistence farmers should exploit the fact that their labor costs are the lowest in the world, giving them a comparative advantage in growing and selling high-value, intensely farmed crops.

I saw firsthand the need for a small-scale strategy in 1981 when I met Abdul Rahman, a farmer in the Noakhali district of Bangladesh. From his three quarter-acre plots of rain-fed

CROSSROADS FOR AGRICULTURE AND WATER

THE PROBLEM:

- Although the Green Revolution significantly increased worldwide grain harvests, hunger and poverty stubbornly persist in Africa, Asia and Latin America. Farmers working small plots of marginal land cannot grow enough food to support their families.
- In sub-Saharan Africa alone, more than 300 million people survive on $1 a day or less. In India, more than 200 million people are malnourished.

THE PLAN:

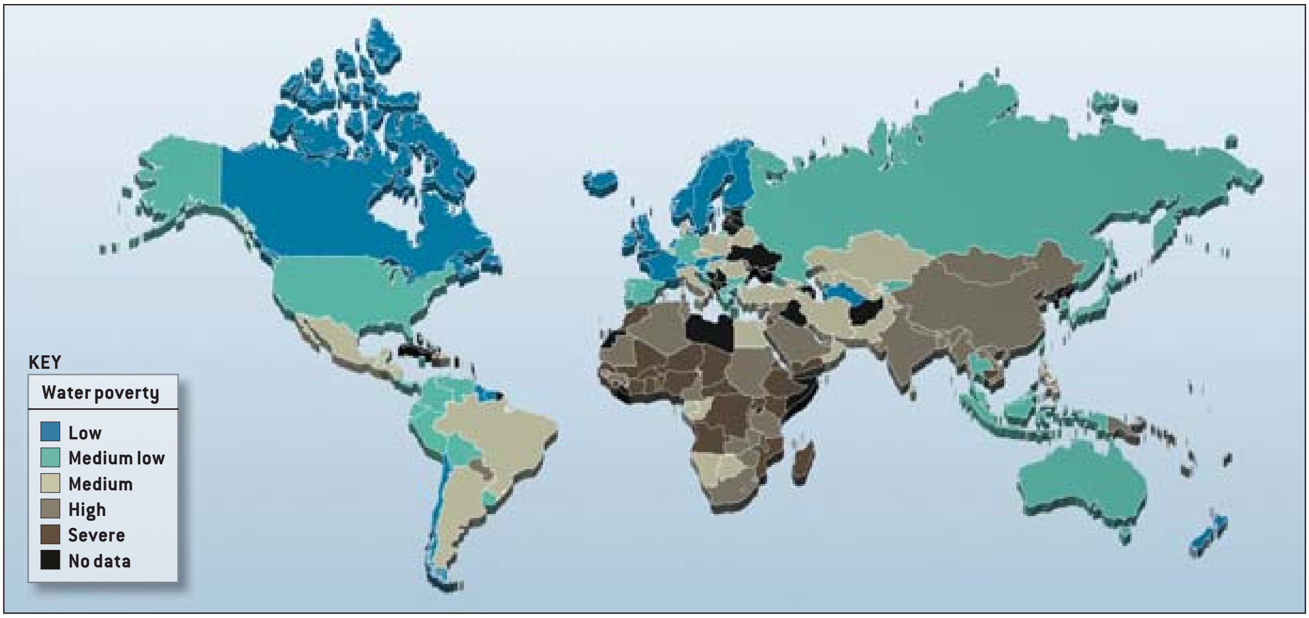
- Continued improvements in the productivity of large farms will expand the overall food supply, but efforts to reduce poverty should focus on increasing the incomes of small farmers.
- Individual irrigation systems employing inexpensive equipment, such as drip lines and storage tanks, can greatly enhance the yields of small plots. If farmers raise high-value crops such as tomatoes or chili peppers, they can boost their earnings by as much as $500 a year.

Growing marketable crops

PRECEDING PAGE: KENN BROWN (*photoillustration*) AND INTERNATIONAL DEVELOPMENT ENTERPRISES (*photograph*); THIS PAGE: IDE

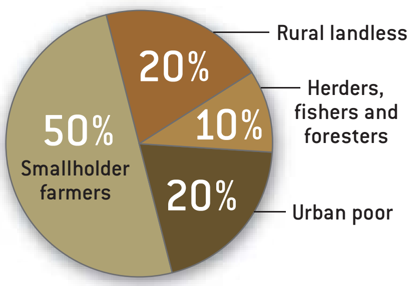
WATER AND POVERTY

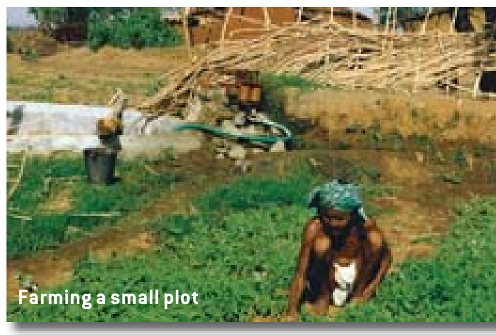
Because water is so vital to agriculture, the lack of it has become one of the most important causes of poverty in the developing world. Researchers at the Center for Ecology and Hydrology in Wallingford, U.K., have developed an index that shows the effects of water scarcity by combining data on availability and access with information on water use and quality. Most of the countries with the greatest water poverty are in sub-Saharan Africa, but the problem is also dire in China, India and Bangladesh.



WATER SCARCITY takes its highest toll on small farmers, many of whom must eke out a living in semiarid areas far from wells or reservoirs. About half the world's hungry people are farmers who work small plots of land; another 20 percent are landless farm laborers who live in rural regions.

WHO ARE THE HUNGRY?





Farming a small plot

rice fields, Abdul could grow only 700 kilograms of rice each year—300 kilograms less than what he needed to feed his family. During the three months before the October rice harvest came in, Abdul and his wife had to watch silently while their three children survived on one meal a day or less. As I walked with him through the scattered fields he had inherited from his father, I asked what he needed to move out of poverty. "Control of water for my crops," he said, "at a price I can afford."

Soon I learned about a simple device that could help Abdul achieve his goal: the treadle pump. Developed in the late 1970s by Norwegian engineer Gunnar Barnes, the pump is operated by a person walking in place on a pair of treadles made of bamboo or another locally available material. The human-powered pump can irrigate half an acre of vegetables and costs only $25 (including the expense of drilling a tube well down to the groundwater). Abdul heard about the treadle pump from a cousin and was one of the first farmers in Bangladesh to buy one. He borrowed the $25 from an uncle and easily repaid the loan four months later. During the five-month dry season, when Bangladeshis typically farm very little, Abdul used the treadle pump to grow a quarter-acre of chili peppers, tomatoes, cabbage and eggplants. He also improved the yield of one of his rice plots by irrigating it. His family ate some of the vegetables and sold the rest at the village market, earning a net profit of $100. With his new income, Abdul was able to buy rice for his family to eat, keep his two sons in school until they were 16 and set aside a little money for his daughter's dowry. When I visited him again in 1984, he had doubled the size of his vegetable plot and replaced the thatched roof on his house with corrugated tin. His family was raising a calf and some chickens. He told me that the treadle pump was a gift from God.

Bangladesh is particularly well suited for the treadle pump

BRYAN CHRISTIE DESIGN; SOURCE: C. A. SULLIVAN AND J. R. MEIGH *Center for Ecology and Hydrology* (*map*); JEN CHRISTIANSEN (*pie chart*); IDE (*photograph*) because a huge reservoir of groundwater lies just a few meters below the farmers' feet. In the early 1980s IDE initiated a campaign to market the pump, encouraging 75 small private-sector companies to manufacture the devices and several thousand village dealers and tube-well drillers to sell and install them. Over the next 12 years one and a half million farm families purchased treadle pumps, which increased the farmers' net income by a total of $150 million a year. The cost of IDE's market-creation activities was only $12 million, leveraged by the investment of $37.5 million from the farmers themselves. In contrast, the expense of building a conventional dam and canal system to irrigate an equivalent area of farmland would be in the range of $2,000 per acre, or $1.5 billion.

SMALL-SCALE IRRIGATION

1,500,000
Bangladeshi farmers who have purchased treadle pumps

$49.5 million
Total investment in the pumps

$150 million
Total increase in the farmers' annual income

$1.5 billion
The cost of irrigating the same farmland with a conventional dam and canal system

In terms of reducing poverty, the treadle pump has proved superior to more technologically advanced irrigation schemes. Starting in the 1970s, for example, the World Bank made low-interest loans enabling the government of Bangladesh to import diesel pumps for deep tube wells, a technology used in Nebraska to pull water out of the Ogallala aquifer. Each system cost $15,000 and could irrigate 40 acres. The government made them available to farmers for free. Another loan program allowed the government to import 10,000 diesel pumps for shallow wells, each of which cost $900 and irrigated 12 acres. Bank appraisers rated the program a success because it moved Bangladesh closer to rice self-sufficiency, but when the government subsidies ran out, farmers abandoned most of the deep wells because of their high operating costs. The shallow wells remained popular among larger, richer farmers, who became water lords and put many small farmers out of business.

The cost per irrigated acre was $375 for the deep diesel pumps, $133 for the shallow diesel pumps and only $66 for the treadle pumps—$50 of which came from the farmers. By focusing on creating a sustainable market, the treadle-pump project produced more income and left a gentler footprint on the environment. A similar approach is now needed to address the problem of naturally occurring arsenic in Bangladesh's groundwater, which is poisoning farmers. Because many Bangladeshis are willing and able to pay for a $7 household filter to rid their drinking water of arsenic, the obvious solution is to find private-sector distributors and subsidize purchases for those who cannot afford it. (IDE's organization in Bangladesh is currently promoting the filter.) As usual, though, the government and the donor community are calling for large-scale solutions such as centralized piped-water systems, which have not been effective in Bangladesh in the past.

Drop by Drop

OBTAINING WATER from wells or reservoirs is only half the challenge; farmers must also find better ways to deliver the water to their crops. Most irrigated farms in the developing world rely on inefficient surface-flooding methods that have remained unchanged for centuries. As a result, millions of acres of good cropland have been lost to waterlogging, salinization and excessive pumping from aquifers. The poorest farmers face an additional problem: many work on marginal land in semiarid areas. Some have limited access to surface water or wells, and others are totally dependent on rainfall. Drip irrigation, one of the most miserly ways of applying water to crops, would be a godsend for them, but most drip systems are too big, complicated and expensive to fit their needs.

In 1992 I visited a hill village in Nepal called Madan Pokhara where sprinkler systems supplied from small reservoirs irrigated the farms. I was disappointed to learn that the systems, each of which served three farmers, cost $1,000 apiece. I resolved to find a way to make it cheaper. I discovered that just about every other house in the village got its washing water from a small plastic pipe stuck in a stream above the house. Why not use the same cheap piping to bring water from streams to crops? We could replace the expensive reservoirs of the sprinkler system with used 55-gallon drums sunk in the stream. To replace the sprinklers, we could punch holes in the pipe with a hammer and nail and let water dribble out to the plants. I thought I was pretty smart until I ran this idea past Dan Spare, an irrigation engineer building a canal in Nepal's Kali Gandaki River basin. "You have just invented drip irrigation," he said. "The only problem is that the Israelis invented it 35 years ago."

I was convinced that drip irrigation could be tailored to the needs of subsistence farmers. In 2001, after seven years of development and field tests, IDE introduced an effective, low-cost drip system that resisted clogging and sold for one fifth the price of conventional equipment. Families could invest as little as $3 to buy a kit that irrigated a 40-square-meter kitchen garden, then reinvest some of the 300 percent annual return it generated to expand the system's coverage up to an acre or

TREADLE PUMPS have been adopted by many small farmers in Bangladesh and India because they cost only $25. A farm family using the pump to irrigate a half-acre plot can earn several times that amount in just the first season by selling the vegetables they grow. This Indian family is raising hot peppers. Treadle pumps are well suited for regions where the water table is relatively close to the surface.

IDE

more. In 2004 farmers in India purchased enough IDE equipment to irrigate 20,000 acres. Within 10 years I expect that low-cost drip systems will irrigate several million hectares in India alone, an amount larger than the total worldwide area under drip irrigation today.

Drip systems can also be used to irrigate crops with stored rainwater. Throughout history, farmers have devised ways to collect the copious water rushing off the fields during the monsoons that batter East Africa and South Asia every year. IDE is now developing a system that employs small settling ponds to remove silt from the rainwater, which is then diverted to an enclosed 10,000-liter storage tank. In the ensuing months, farmers use a hand pump to send water through the drip piping to their crops, which can be sold for high prices during the dry season. Because this system carries out the functions of a big dam for a small farm, we gave it the ironic name of NAWSA MAD, which is Aswan Dam spelled backward. (Aswan is perhaps the most controversial of the big dam systems in the developing world.) NAWSA MAD's storage tank, which will cost only $40, is undergoing final field tests in India and Africa.

THE AUTHOR

PAUL POLAK

POLAK is founder and president of International Development Enterprises (IDE), a nonprofit grassroots organization that has brought more than 12 million people living on small farms out of poverty since 1981. Earlier in his career, Polak was an entrepreneur and a practicing psychiatrist who received his M.D. from the University of Western Ontario in 1958; he developed a model of direct intervention for treating major mental illness, writing 80 scientific articles and book chapters on the topic. Polak recognized the links between mental illness and poverty, and his success as an entrepreneur enabled him to start IDE, which is based in Lakewood, Colo.

To Dam or Not to Dam?

PEOPLE USE ONLY about 10 percent of the freshwater that falls on our planet; the other 90 percent falls in underpopulated places such as the Amazon or comes all at once during rainy seasons and rushes past farmers' fields to the sea. The easiest way to produce more food for a growing population is to use the existing supply of irrigation water more productively, but that is not the only answer. Farmers currently use

DRIP IRRIGATION brings water to vegetables grown in the hill villages of Nepal (*top*). International Development Enterprises was able to make the system affordable by using cheap plastic piping. The drip lines deliver water directly to the roots of the crops (*bottom*).

IDE

about 2,500 cubic kilometers of water every year, and the consensus is that even with improvements in productivity they will require about 20 percent more by 2025.

I have been a vocal critic of big dams that are built mindlessly, but I believe it would be a mistake to halt all dam construction. Careful planning is the key. The World Commission on Dams recently released a report that offered sensible procedures for mitigating the negative impacts of dams on the environment. The report also advocated examining alternatives to dams such as storing water underground, which eliminates evaporation losses and provides water closer to where it is needed.

In many places, groundwater tables are dropping two meters a year or more because of overpumping. Some aquifers can be replenished, though, by trapping monsoon rainwater and directing it underground. The state of Gujarat in India is a good example: it is hot and dry most of the year, and most of its rain falls during the monsoon season, when flooding is common. Starting in the 1980s, a Hindu religious movement called Swadhyaya Parivar led thousands of farmers in Gujarat to build waterways that direct monsoon runoff into large open wells. This collective action restored groundwater aquifers and significantly increased agricultural productivity. Development agencies should immediately conduct hundreds of Gujarat-type experiments and launch a major global initiative to scale up the most successful ones.

Another promising idea is to use drip and sprinkler systems in combination with the irrigation canals that lace croplands in India, China and other countries. Farmers on canals can get water only when their turn comes, and canal systems typically deliver water every two to three weeks, instead of the two- to four-day cycle that most high-value crops thrive on. Installing small storage tanks along the canals would enable farmers to irrigate their fields between the scheduled times of water delivery. Farmers in China are already successfully adopting this system, which they call "melons on a vine." In addition to increasing the amount of food grown and money earned for each liter of water, such efforts alleviate the damaging effects of waterlogging and salinization, both of which are made much worse by applying too much water at once.

New irrigation systems for farmers could also provide clean drinking water to many of the 1.1 billion people who lack access to it. Because more than 80 percent of these people live in poor rural areas rather than cities, building large, centralized, piped-water complexes to serve them all would be impractical and prohibitively expensive, costing hundreds of billions of dollars. But a system that combines irrigation with delivering drinking water can actually pay for itself. In 2004 IDE's organization in Nepal built small water-supply systems in eight hill villages. In addition to providing drinking water from clean springs for 10 to 15 families, each system delivered enough water to drip-irrigate several plots of off-season vegetables. We expect that the sales of these vegetables will pay for the water systems within one to two years and provide continuing income for the families after that.

In much of Africa, rural villagers get water for both drinking and irrigation from nearby wells. Unlike the situation in Bangladesh, the water table is too deep to be accessed by treadle pumps. Hand pumps make it easier to get the water out of the ground, but most Africans cannot afford the $1,500 installation cost. (The hand pump that Peter Mwete used to obtain water for his plot in Marimari was donated to his village by a church group.) If the villagers form a water-users group, however, they can borrow the money for the hand pump. Assume that each of 30 families agrees to pay the group $7 a year for clean drinking water and that 15 of the families invest an additional $20 each to buy drip-irrigation systems. Each farming family earns an extra $100 a year from selling fruits and vegetables, out of which $30 is given to the water-users group. The group collects $210 a year from the water users and $450 a year from the farmers, which is enough to cover operating expenses and pay off the $1,500 loan in four years.

It is absolutely essential that the rural poor invest their own time and money in the effort to move out of poverty.

African governments and development agencies can encourage such arrangements by organizing the water-users groups, training the farmers and facilitating their access to markets. This strategy is much more effective than subsidizing the cost of installing the hand pumps, because the villagers are more likely to properly maintain the pumps if they own them. Of course, this approach may not work for every village; in some cases, for example, the wells may not produce enough water for both drinking and irrigation. But I believe that at least half the new rural drinking-water systems can be self-financing.

The Price Tag

HOW MUCH WILL IT COST to feed three billion more people and cut poverty levels in half? All one can do is make an educated guess. On larger farms with good soils, where most of the gains in agricultural productivity have been made so far, I estimate that boosting harvests further will require a total investment of $20 billion over the next 10 years. It will take about $10 billion to support the continuing agricultural research at universities, national institutions and the centers in the Consultative Group on International Agricultural Research. Another $10 billion or more will be needed to double the productivity of existing irrigation systems and to build a small number of new large dams.

Reducing poverty, however, is more complicated than simply expanding the food supply, and estimates of the cost of achieving the Millennium Development Goals vary widely. Jeffrey D. Sachs of Columbia University and his committees of United Nations experts say wealthy countries must provide a total of more than $1.5 trillion of assistance funds to developing nations over the next 10 years, with the lion's share devoted to improving health, education, energy and road infrastructure [see "Can Extreme Poverty Be Eliminated?" by Jeffrey D. Sachs, on page 56]. My work with IDE, however, leads me to a different set of conclusions. First, although investments from the West are critical to prime the pump, it is absolutely essential that the rural poor invest their own time and money in the effort to move out of poverty. The crucial step is releasing the energy of Third World entrepreneurs. The good news is that one-acre farmers are already entrepreneurs and are surrounded by thousands of other businesspeople operating small stores and repair shops.

For each of the past several years, IDE's projects have increased the net annual income of more than 100,000 poor rural families by $500 at a cost of less than $200 per family. Assuming that pace can continue, reaching the Millennium Development Goals—which require bringing some 600 million people, or about 100 million families, out of poverty—would cost $20 billion. This investment would not cover all the infrastructure improvements that Sachs and others have advocated, but it would give rural families new income to educate their children and improve their farms, homes and health. What is more, I am confident that such a program would spur private agribusinesses to make a similar investment to build a market infrastructure for processing, grading, packaging and distributing the tomatoes, eggplants, chili peppers and other high-value produce grown by the newly empowered farmers.

If a small organization such as IDE, with an annual budget of $10 million and a staff of 600, can bring nearly one million people out of poverty every year, then surely the combined efforts of the wealthy nations can do much more. But development agencies must be willing to start at the bottom—at the level of the small farmer walking quietly on his treadle pump—and work their way up. SA

MORE TO EXPLORE

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More information about International Development Enterprises and its work can be found at **www.ide-international.org** and **www.iwmi.org/respages/PGW/treadle.htm**

PUBLIC HEALTH IN TRANSITION

BY BARRY R. BLOOM

Chronic disorders such as heart disease and diabetes, once common only in the industrial nations, are now sweeping the rest of the globe. Meanwhile the threat of infectious diseases still looms large. New public health priorities are urgently needed

EXPANDING WAISTLINES and associated health problems are a rising concern in Malaysia and in many developing nations.

Not long ago Stephen Lewis, United Nations special envoy for HIV/AIDS in Africa, toured Zimbabwe. He stopped by an elementary school and asked the children what most troubled them. Their answers were revealing for their bleakness: seven out of 10 replied, "Death."

Lewis then traveled to Zambia, where he saw fields of cabbages. He asked the villagers whether they had enough to eat. "Yes," they told him, "we even have cabbages to sell." "What do you do with your profits?" he asked. "We buy coffins," they replied.

For people in wealthy countries, such stories reinforce an image of the developing world, one in which death dominates the landscape. Yet that world, home to 83 percent of the planet's population, is a vast and diverse place. Across much of the globe, stereotypes of death-ravaged countries no longer match reality. On every continent, a remarkable demographic transition is occurring: rural populations are moving to urban areas, women are bearing fewer children, and populations are growing older. Accompanying this trend is an epidemiological transition: countries undergoing rapid economic expansion, such as India and China, are now confronting health problems similar to those of the U.S.

In fact, many nations have lessened the impact of infectious disease and improved the health of their people by providing access to vaccines, clean water, basic medical services and good nutrition. People in most developing countries are living longer and increasingly dying not from infection but from the chronic conditions common among the aged: heart disease, diabetes and cancer. Today chronic disorders are the greatest contributor to the global burden of disease.

Infectious diseases are far from gone, however; they remain a threat not just to Africa but to all countries, including the U.S., where antibiotic resistance is a growing menace and where 45 million people, lacking health insurance, are vulnerable to readily treatable diseases. Threats from new infectious agents also draw the world's nations together. In this era of globalization, pathogens eschew national borders and can spread across the planet at jet speed. Indiscriminate in where they choose to settle, they represent a real danger to humanity, one that no nation can deal with by itself.

As a consequence, an extraordinary convergence is taking place. No longer is the world cleaved in two, with developing countries roiled by infectious disease and industrial nations largely isolated from its scourges. Healthwise, the Northern Hemisphere and the Southern Hemisphere outside of sub-Saharan Africa are more alike than different.

Instead the world is divided along other lines. Within countries and within regions, the divisions between rich and poor, healthy and diseased, remain sharp. In the poorest nations, half the children die before age five. In parts of the U.S., the health disparities are also shocking. Native Americans living in certain parts of South Dakota can expect to die some 13 years before white Americans of the same age in parts of Minnesota. About 88 percent of white men in the U.S. reach age 65; only 76 percent of African-American men do.

In a world where great strides are being made in the prevention and treatment of disease, such inequity is morally unacceptable. It is also economically unwise. Poor health can retard economic

CROSSROADS FOR PUBLIC HEALTH

THE PROBLEM:

- Health disparities between rich and poor are widening.
- The future of public health is far from secure. Globally, infectious disease is waning, but chronic disorders are taking an increasing toll. Many chronic ills are related to lifestyle and are unlikely to abate without action by regulatory and public health agencies.
- A deadly pandemic, an act of bioterrorism or an environmental calamity could precipitate crisis.

THE PLAN:

- Prevention is paramount to securing a healthy future, and simple strategies are highly effective against many infectious and chronic diseases.
- With good data and proper analytical tools, priorities can be set, thus helping to provide maximal benefits for a maximal number of people.
- Concerted effort and multilateral collaboration can eradicate pockets of disparity, bringing basic health care to those now lacking it, and can ease air and water pollution.
- International crises, such as pandemics and natural disasters, can be minimized by building a global public health infrastructure able to respond quickly and efficiently to emerging threats.

CLINIC in Mali, Africa

STUART FRANKLIN *Magnum Photos* (*preceding pages*); ABBAS *Magnum Photos* (*this page*)

CHANGING PATTERNS OF GLOBAL HEALTH

PRIME SOURCES OF DALYs (disability-adjusted life-years)—healthy years lost to injury, illness or premature death worldwide—are changing (*table*). They are shifting from acute infections to other influences, including conditions related to aging and behavioral choices. By 2020 heart disease, depression and vehicular accidents are expected to become the top three sources of DALYs. The accident in the photograph occurred in Hangzhou, China, earlier this year.

LEADING CAUSES OF DALYs

Rank	1990*	2020 Projection
1	Pneumonia and other respiratory infections	Heart disease
2	Diarrheal disease	Depression
3	Disorders of childbirth and newborns	Vehicular accidents
4	Depression	Stroke
5	Heart disease	Emphysema and bronchitis
6	Stroke	Pneumonia and other respiratory infections
7	Tuberculosis	Tuberculosis
8	Measles	War
9	Vehicular accidents	Diarrheal disease
10	Congenital defects	HIV

*Based on 1990 data later reanalyzed as DALYs

AP PHOTO/CHINATOPIX; SOURCES FOR DATA: CENTERS FOR DISEASE CONTROL AND PREVENTION AND HARVARD SCHOOL OF PUBLIC HEALTH

growth, and good health can drive growth, stem poverty and promote social equity. Moreover, the costs of health problems in one place can spill into others (as the 2003 SARS outbreak in Asia demonstrated).

The gap between what we know about the new realities of public health and how we translate that knowledge into action is huge. Addressing the health problems of every country will require international cooperation and a global coordinating architecture that is not yet in place.

A Chronic Burden

A SHORT WHILE AGO mortality was the only measure used by the World Health Organization (WHO) to describe health. A person was either dead or alive. Those who were somewhere in between, suffering from ongoing illness or injury and often unable to work, were statistically invisible. Public health officials could neither track people affected by disability nor monitor the social and economic impact of their disorders.

With the help of sophisticated analytical tools, WHO now has a solid grasp not only of chronic disease but also of the hardships such afflictions impose on society. Indeed, the data it has amassed, so-called quality-of-life indicators, have played a key role in helping epidemiologists forecast trends, corral contagions, monitor patterns of disease and meaningfully compare the burden imposed by persisting conditions to that imposed by infectious disease. Having such information in hand enables countries to establish their health priorities.

Among the most powerful tools is an application of metrics called disability adjusted life-years, or DALYs. These statistics tabulate the number of healthy years lost to injury, illness, and premature death and can be broken down in numerous ways: by disease, region, age, gender and so on. By allowing the effects of disease to be accurately tallied and tracked, DALYs have opened a new era in preventive health care.

In 1999, the first year for which DALYs were collected, some 56 million people died worldwide, but the equivalent of 1.4 billion healthy years were lost to survivable but disabling conditions—a far higher number than epidemiologists had predicted. Sub-Saharan Africa, home to only 10 percent of the world's

NURSING STUDENTS who train in Mexico (*photograph*) often end up working in the U.S. This kind of brain drain to rich nations can undermine the stability of health care systems in developing nations.

population, accounted for 26 percent of the healthy years of life lost, largely because of infectious disease, especially HIV/AIDS.

DALYs also provide a stark analysis of unhealthy behaviors and the toll they impose on society. In the U.S., half of all deaths in any given year—some 1.2 million—are related to tobacco, alcohol, poor diet and lack of exercise. Worldwide, tobacco addiction alone kills some five million people a year and shackles millions more with heart, lung and circulatory problems. And obesity, which is reaching epidemic levels, contributes to coronary artery disease, diabetes, depression and a host of other serious conditions. Moreover, workplace-related deaths and injuries are skyrocketing in developing countries, where production goals and abundant labor too often compromise worker safety. Although exact numbers are hard to come by, the International Labor Organization estimates that on-the-job fatalities in China are five times more common than in the U.S. and that injury rates are considerably higher.

If current trends continue (barring unforeseen calamity), by 2020 global rates of infectious diseases, such as diarrhea, pneumonia and tuberculosis, will decline relative to chronic diseases. Mental illness, particularly depression (which accounts for relatively few deaths but much disability), will increase, occupying second place on the list of contributors to the world's burden of disease. Heart disease will hold first place, and, surprisingly, vehicular accidents will climb to third—being especially numerous in countries that lack (or poorly enforce) licensing, registration and inspection requirements. At the same time, rates of obesity, tobacco-related disease and industrial accidents will continue to ascend, threatening gains made elsewhere in health care.

Prevention Is Key

PREVENTION MUST BE paramount in the war against chronic and infectious disease. Not only is prevention more powerful than treatment in reducing morbidity and mortality, but simple strategies can also produce big gains. Consider the 2004 tsunami, a horrific calamity by any measure. Emergency help was badly needed, outbreaks of infectious disease loomed, and time was short. Public health officials feared a second round of deaths greater than the first. But by setting realistic goals and coordinating relief efforts, they were able to quickly amass the essentials—bottled water, vaccines, mosquito nets—and so thwart the spread of cholera, measles and dysentery. Ironically, when public health interventions succeed, as they did in the wake of the tsunami, there is little to show. Absence defines success in the public health realm.

Elsewhere, targeted efforts to bring vaccinations, antibiotics and nutrition to millions—along with improved sanitation—have dramatically reduced the number of deaths from infectious disease, as much as 60 percent in some regions. Today major immunization campaigns are under way to meet WHO's and the U.N. Millennium Development Project's goals of vaccinating all youngsters against childhood diseases, particularly in Africa. Also, countries such as India and China have launched National Immunization Days, with extraordinary results. In just one week in November 2004, 2.5 million volunteers immunized 167 million Indian children. In addition to prolonging life, vaccination makes tremendous economic sense. For every dollar the U.S. spends on diphtheria, pertussis and typhus (DPT) vaccines, an estimated $29 is saved in medi-

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MARCO UGARTE *AP Photo*

cal costs; for measles, mumps and rubella (MMR), the return averages $21—a bargain by any measure.

Prevention programs targeted at HIV/AIDS have also been highly effective in the U.S. as well as in Uganda, Thailand and Brazil. All prove that, with concerted effort, this disease can be averted and controlled on a national scale. The increasing availability of antiretroviral drugs, many now provided at cost by pharmaceutical companies, will keep people who are HIV-positive alive and, in offering hope, will increase interest in voluntary testing. By linking treatment to the prevention of transmission, these key strategies could help shift HIV infection from an invariably fatal disease to a chronic illness worldwide. But national leadership, educational programs, and a major effort to mobilize the people and the media are needed. Time is of the essence: HIV/AIDS is spreading not just across Africa but also throughout India, South Asia and eastern Europe.

Prevention efforts focused on chronic diseases associated with aging have scored some big successes, too. One need only look to the U.S., where over the past 20 years antihypertensive medications, along with diet and exercise, have reduced deaths from heart attacks and strokes by 50 and 30 percent, respectively. Because many key drugs for treating heart disease—aspirin, beta blockers, statins and ACE inhibitors—are now off-patent and thus relatively inexpensive, similar reductions could theoretically be achieved worldwide. And the Human Genome Project is helping to identify genes associated with health and disease and to assess genetic influences on responses to pharmaceuticals and environmental factors. This research, in turn, is expected to spawn a new era of targeted drugs and therapies, maximizing health care and improving the lives of those with chronic diseases.

For both adults and children, a critical approach to protecting health—albeit a politically difficult one—is combating tobacco use. Smoking is not an individual choice; it is an addiction. Powerful social pressures and advertising lure individuals into smoking. And physiology takes over from there: nicotine is one of the most addictive substances known. Governments must lead the charge, such as by mounting media campaigns aimed at preventing young people from starting to smoke and by enacting policies and laws that prohibit cigarette advertising and ban smoking in public places.

For children, two other preventive strategies would vastly improve health: feed those who are malnourished and provide them with vitamins and minerals; limit weight gain in those who are overnourished.

Prevention is obviously crucial as well in dealing with emerging infectious diseases; it is better to stop them before

NO PLACE TO HIDE

EMERGING DISEASES

1973	Rotavirus
1977	Ebola virus
1977	Legionnaire's disease
1981	Toxic shock syndrome
1982	Lyme disease
1983	HIV/AIDS
1991	Multidrug-resistant tuberculosis
1993	Cholera caused by strain 0139
1994	*Cryptosporidium* infection* (large outbreak in Wisconsin)
1998	Avian flu
1999	West Nile virus* (first U.S. appearance)
2003	SARS (severe acute respiratory syndrome)
2004	Marburg virus* (largest outbreak, in Angola)

NEW INFECTIOUS DISORDERS, against which humans have little immunity, are the wild cards of public health; those in the table are listed according to when the causative agent was reported or when a notable reemergence (*asterisk*) occurred. Except for HIV/AIDS, none has wrought global devastation, but that good fortune may not hold. Epidemiologists fear avian flu in particular, saying it is only a matter of time before a deadly strain moves readily from person to person, unleashing a global pandemic. To try to prevent a pandemic, workers in Vietnam last January culled thousands of chickens at a farm where birds showed flu symptoms (*photograph*).

HOANG DINH NAM *AFP/Getty Images*

EIGHT CRITICAL STEPS

No single fix applies to all places, but implementation of the following recommendations would make a huge difference to health around the globe.

1 Control tobacco advertising, sales and addiction.
This is the single most effective way to prevent disease in both rich and poor countries. Recently 192 countries, including the U.S., signed the Framework Convention on Tobacco Control treaty. Sponsored by the World Health Organization, the treaty sets goals for reducing advertising and sales of tobacco to children, recognizing that if kids can avoid smoking until age 24, 95 percent will never smoke. The challenge now is to support efforts to reach those goals.

2 Put children atop the global agenda.
Two conceptually simple strategies would significantly reduce disease and disability among children: feed those who are undernourished adequate calories and nutrients; provide balanced diets and greater opportunities for exercise to those who are overnourished. And immunize all children.

3 Reduce health disparities by supporting the United Nations Millennium Goals for health.
These goals, designed to create a safety net for all, prescribe a basic package of health interventions—including childhood vaccination, treatment for AIDS, tuberculosis and malaria, and steps for reducing pregnancy-related deaths.

4 Integrate metrics into all aspects of health care planning.
Data on years lost to disability, injury and premature death help to clarify how nations can get the most out of their health care dollars, and the information can be used to hold governments accountable for the well-being of their populations.

12-YEAR-OLD SMOKER in China

5 Stop the brain drain.
Students who go overseas for medical training need incentives to return home. Rich countries must support the training of health care workers in poor countries, help create conditions conducive to their staying and compensate countries whose health workers do leave. What good are all the drugs and vaccines in the world, if no one is there to administer them?

6 Invest in an infectious disease surveillance system.
A system that recognizes all health threats—including bioterrorism and emerging infectious diseases—is essential. In addition, governments need to foster collaborations with and among departments of health, so that immediate steps can be taken in response to identified threats.

7 Reduce threats posed by environmental sources.
An international agency needs to set global standards for air and water pollution and also assess the economic impact of chronic illnesses caused by these threats.

8 Develop a global health architecture.
Because of its inherent complexities, global health will improve only if new partnerships form among governments, nongovernmental organizations, industrial groups and universities. Health care is interconnected with education, finance, transportation, trade, immigration, communication and the environment. Clearly, the global burden of disease cannot be fixed by the public health sector alone. *—B.R.B.*

they begin to spread. A highly contagious pathogen traveling swiftly can render quarantine efforts ineffective. We need strong global as well as national surveillance systems capable of reacting quickly to perceived threats, systems that can recognize both naturally arising diseases and agents of bioterrorism.

We also need laboratories that can identify unknown microbes and health departments capable of multilateral communication and coordination. So far we have been lucky: recent outbreaks of new diseases—namely, SARS in Asia and Ebola in Africa—have been mercifully limited. But we must remain vigilant; it is only a matter of time before a decimating pathogen will make its appearance.

Inadequate Infrastructure

JUGGLING ALL THESE priorities is difficult in its own right, but the situation is made worse by the inadequacy of public health systems on a global scale. The tsunami of 2004 brought this need to light in a most vivid way. Government and international relief agencies jumped into action immediately, but they had no central authority to turn to. There was no existing infrastructure to handle a disaster of such international dimensions, no designated command center, no prepared list of key people or agencies to call. For all the strides made in public health in recent years, when the tsunami hit, no one had a set game plan for orchestrating a recovery effort that involved more than five countries, a range of health and environmental problems, and economic and structural devastation.

Likewise, no global architecture exists to deal with other health threats that cross national boundaries. Health ministers alone cannot protect their nations. Asthma in the U.S., for example,

AP PHOTO

may be exacerbated by coal-burning power plants in China; if so, prevention is possible only if China's prime minister and energy minister are part of the solution. Similarly, if global warming triggers the spread of malaria northward, then efforts to abate climate change by reducing greenhouse gases will require the engagement of the U.S. president. The world needs an infrastructure that enables decision makers to address health, economics, the environment and national security in an integrated way.

Just as an international infrastructure is needed to deal with global health threats, each country should have its own public health system—that is, its own department of health, medical schools and staffed clinics. Unfortunately, qualified health personnel—along with the institutions, such as universities and medical centers, needed to train them—are a missing keystone in many places.

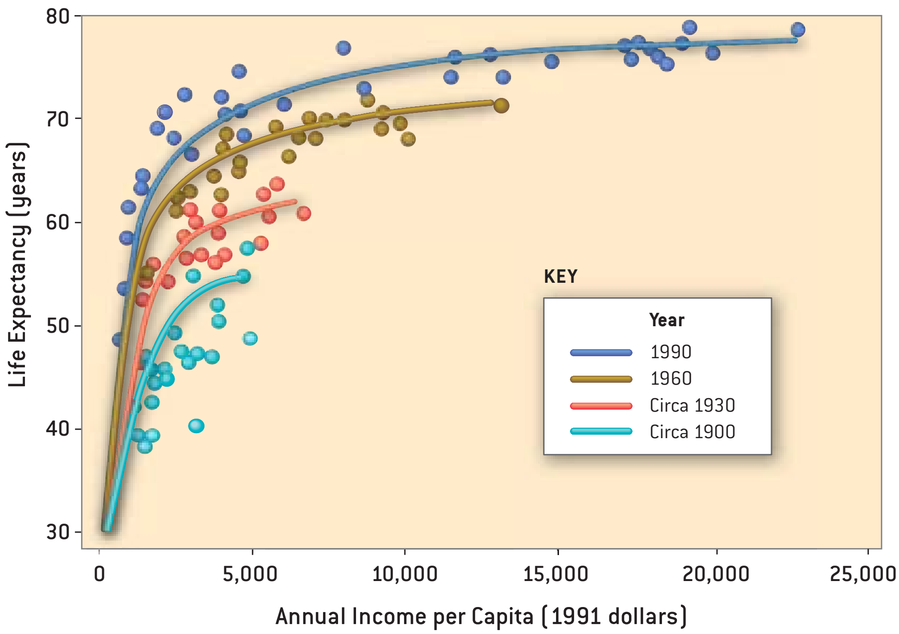
Exacerbating the problem is a brain drain. Many health care workers in developing countries are emigrating to wealthier countries, drawn by higher wages and better working conditions. The statistics speak for themselves. In one year, 30 percent of Zambia's nurses emigrated to the U.K.; even more leave the Philippines every year. In Malawi, where most health care workers either emigrate or fall prey to infectious diseases themselves, three fourths of nursing jobs are unfilled. In South Africa, so many professionals have fled that positions for some 4,000 doctors and 32,000 nurses sit vacant.

At the Crossroads

HOW HEALTH WORKERS, political leaders and public health institutions respond to these challenges will determine in large part what the world will be like in 2050 and beyond. Will the struggle to bring health, stability and a decent standard of living to people ensnared by disease and poverty be successful? Will the medical knowledge and technologies taken for granted in developed countries reach those who lack even such basics as clean water, much less antibiotics? Will we live in a world beset by rising rates of morbidity and mortality and ravaged by increasing disparity and inequality? Or will we have made significant progress in promoting good health, equitable health care and opportunities for economic growth in all countries of the globe?

The international, national and local infrastructures needed for optimal health for the majority of people on the planet are sorely lacking—as, in many quarters, is a clear vision. No one can predict with absolute certainty what kind of world our children will inherit. But one thing is certain: rapid advances in the life sciences, combined with concerted public health efforts, can contribute significantly to a more sustainable and equitable world. SA

RELATION BETWEEN INCOME AND LIFE EXPECTANCY



WEALTH is important to health, as is evident from the way life expectancy at birth rises with income in the graph above. (A dot represents a nation.) But health is also important to wealth: people who are very poor tend to die early and thus are less able to contribute to their nation's economic development. And money is only one determinant of health. On average, people in the richest nations in 1900 could expect considerably shorter life spans than people in countries having equal income in 1990, in part because they lacked the knowledge derived from modern biomedical and public health research.

SOURCE FOR DATA: *WORLD DEVELOPMENT REPORT*, PAGE 34, 1993 (www-wds.worldbank.org)

MORE TO EXPLORE

Burden of Disease: Implications for Future Research. C. M. Michaud, C.J.L. Murray and B. R. Bloom in *Journal of the American Medical Association,* Vol. 285, No. 5, pages 535–539; February 7, 2001.

Information on emerging infections and U.S. health statistics is available at the Centers for Disease Control and Prevention Web site: **www.cdc.gov**

Millions Saved: Proven Successes in Global Health is at the Center for Global Development Web site: **www.cgdev.org/Publications/millionssaved/**

World Development Report (for various years) is at the World Bank Web site: **www.worldbank.org**

Macroeconomics and Health: Investing in Health for Economic Development and **World Health Report** (for various years) are at the World Health Organization site: **www.who.org**

ECONOMICS IN A FULL WORLD

BY HERMAN E. DALY

The global economy is now so large that society can no longer safely pretend it operates within a limitless ecosystem. Developing an economy that can be sustained within the finite biosphere requires new ways of thinking

Growth is widely thought to be the panacea for all the major economic ills of the modern world. Poverty? Just grow the economy (that is, increase the production of goods and services and spur consumer spending) and watch wealth trickle down. Don't try to redistribute wealth from rich to poor, because that slows growth. Unemployment? Increase demand for goods and services by lowering interest rates on loans and stimulating investment, which leads to more jobs as well as growth. Overpopulation? Just push economic growth and rely on the resulting demographic transition to reduce birth rates, as it did in the industrial nations during the 20th century. Environmental degradation? Trust in the environmental Kuznets curve, an empirical relation purporting to show that with ongoing growth in gross domestic product (GDP), pollution at first increases but then reaches a maximum and declines.

Relying on growth in this way might be fine if the global economy existed in a void, but it does not. Rather the economy is a subsystem of the finite biosphere that supports it. When the economy's expansion encroaches too much on its surrounding ecosystem, we will begin to sacrifice natural capital (such as fish, minerals and fossil fuels) that is worth more than the man-made capital (such as roads, factories and appliances) added by the growth. We will then have what I call uneconomic growth, producing "bads" faster than goods—making us poorer, not richer [*see box on page 103*]. Once we pass the optimal scale, growth becomes stupid in the short run and impossible to maintain in the long run. Evidence suggests that the U.S. may already have entered the uneconomic growth phase [*see box on page 105*].

Recognizing and avoiding uneconomic growth are not easy. One problem is that some people benefit from uneconomic growth and thus have no incentive for change. In addition, our national accounts do not register the costs of growth for all to see.

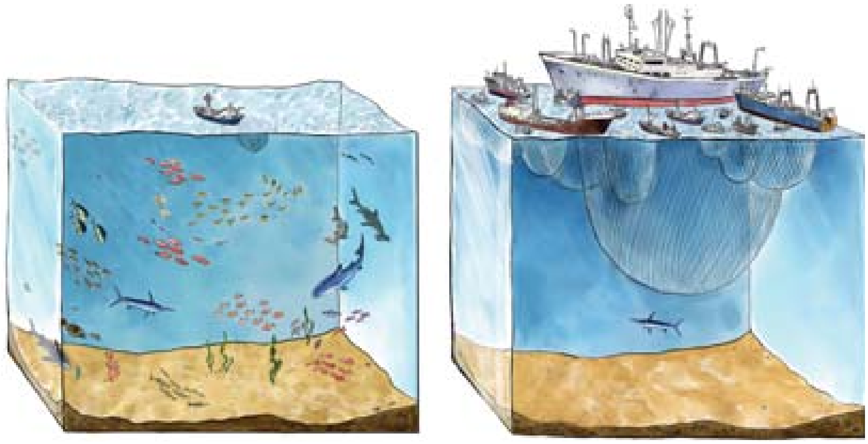
Humankind must make the transition to a sustainable economy—one that takes heed of the inherent biophysical limits of the global ecosystem so that it can continue to operate long into the future. If we do not make that transition, we may be cursed not just with uneconomic growth but with an ecological catastrophe that would sharply lower living standards.

The Finite Biosphere

MOST CONTEMPORARY economists do not agree that the U.S. economy and others are heading into uneconomic growth. They largely ignore the issue of sustainability and trust that because we have come so far with growth, we can keep on going ad infinitum. Yet concern for sustainability has a long history, dat-

MAN-MADE OBJECTS are crowding out the environment. Ways of thinking about the economy that worked well in an empty world no longer suffice in such a full world.

JONATHAN MILNE, REPRESENTED BY WWW.FOLIOART.CO.UK



MAN-MADE CAPITAL cannot substitute for natural capital. Once, catches were limited by the number of fishing boats (man-made capital) at sea (*left*). Today the limit is the number of fish in the ocean (*right*); building more boats will not increase catches. To ensure long-term economic health, nations must sustain the levels of natural capital (such as fish), not just total wealth.

ing back to 1848 and John Stuart Mill's famous chapter "Of the Stationary State," a situation that Mill, unlike other classical economists, welcomed. The modern-day approach stems from work in the 1960s and 1970s by Kenneth Boulding, Ernst Schumacher and Nicholas Georgescu-Roegen. This tradition is carried on by those known as ecological economists, such as myself, and to some extent by the subdivisions of mainstream economics called resource and environmental economics. Overall, however, mainstream (also known as neoclassical) economists consider sustainability to be a fad and are overwhelmingly committed to growth.

But the facts are plain and uncontestable: the biosphere is finite, nongrowing, closed (except for the constant input of solar energy), and constrained by the laws of thermodynamics. Any subsystem, such as the economy, must at some point cease growing and adapt itself to a dynamic equilibrium, something like a steady state. Birth rates must equal death rates, and production rates of commodities must equal depreciation rates.

In my lifetime (67 years) the human population has tripled, and the number of human artifacts, or things people have produced, has on average increased by much more. "Ecological footprint" studies show that the total energy and materials needed to maintain and replace our artifacts has also vastly increased. As the world becomes full of us and our stuff, it becomes empty of what was here before. To deal with this new pattern of scarcity, scientists need to develop a "full world" economics to replace our traditional "empty world" economics.

In the study of microeconomics, the branch of economics that involves the careful measuring and balancing of costs and benefits of particular activities, individuals and businesses get a clear signal of when to stop expanding an activity. When any activity expands, it eventually displaces some other enterprise and that displacement is counted as a cost. People stop at the point where the marginal cost equals the marginal benefit. That is, it is not worth spending another dollar on ice cream when it gives us less satisfaction than a dollar's worth of something else. Conventional macroeconomics, the study of the economy as a whole, has no analogous "when to stop" rule.

Because establishing and maintaining a sustainable economy entails an enormous change of mind and heart by economists, politicians and voters, one might well be tempted to declare that such a project would be impossible. But the alternative to a sustainable economy, an ever growing economy, is biophysically impossible. In choosing between tackling a political impossibility and a biophysical impossibility, I would judge the latter to be the more impossible and take my chances with the former.

What Should Be Sustained?

SO FAR I HAVE DESCRIBED the "sustainable economy" only in general terms, as one that can be maintained indefinitely into the future in the face of biophysical limits. To implement such an economy, we must specify just what is to be sustained from year to year. Economists have discussed five candidate quantities: GDP, "utility," throughput, natural capital and total capital (the sum of natural and man-made capital).

Some people think that a sustainable economy should sustain the rate of growth of GDP. According to this view, the sustainable economy is equivalent to the growth economy, and the question of whether sustained growth is biophysically possible is begged. The political purpose of this stance is to use the buzzword "sustainable" for its soothing rhetorical

CROSSROADS FOR
THE ECONOMY

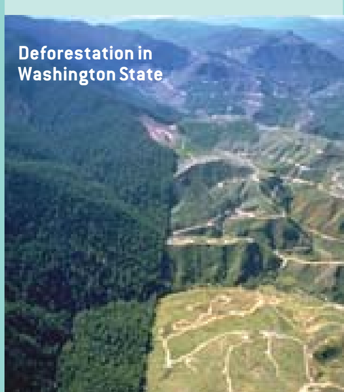
THE PROBLEM:

- The economic status quo cannot be maintained long into the future. If radical changes are not made, we face loss of well-being and possible ecological catastrophe.

THE PLAN:

- The economy must be transformed so that it can be sustained over the long run. It must follow three precepts:

1. Limit use of all resources to rates that ultimately result in levels of waste that can be absorbed by the ecosystem.
2. Exploit renewable resources at rates that do not exceed the ability of the ecosystem to regenerate the resources.
3. Deplete nonrenewable resources at rates that, as far as possible, do not exceed the rate of development of renewable substitutes.



Deforestation in Washington State

DANIEL DANCER (*photograph*); MATT COLLINS (*illustration*) effect without meaning anything by it.

Even trying to define sustainability in terms of constant GDP is problematic because GDP conflates qualitative improvement (development) with quantitative increase (growth). The sustainable economy must at some point stop growing, but it need not stop developing. There is no reason to limit the qualitative improvement in design of products, which can increase GDP without increasing the amount of resources used. The main idea behind sustainability is to shift the path of progress from growth, which is not sustainable, toward development, which presumably is.

The next candidate quantity to be sustained, utility, refers to the level of "satisfaction of wants," or level of well-being of the population. Neoclassical economic theorists have favored defining sustainability as the maintenance (or increase) of utility over generations. But that definition is useless in practice. Utility is an experience, not a thing. It has no unit of measure and cannot be bequeathed from one generation to the next.

Natural resources, in contrast, are things. They can be measured and bequeathed. In particular, people can measure their throughput, or the rate at which the economy uses them, taking them from low-entropy sources in the ecosystem, transforming them into useful products, and ultimately dumping them back into the environment as high-entropy wastes [*see box on next page*]. Sustainability can be defined in terms of throughput by determining the environment's capacity for supplying each raw resource and for absorbing the end waste products.

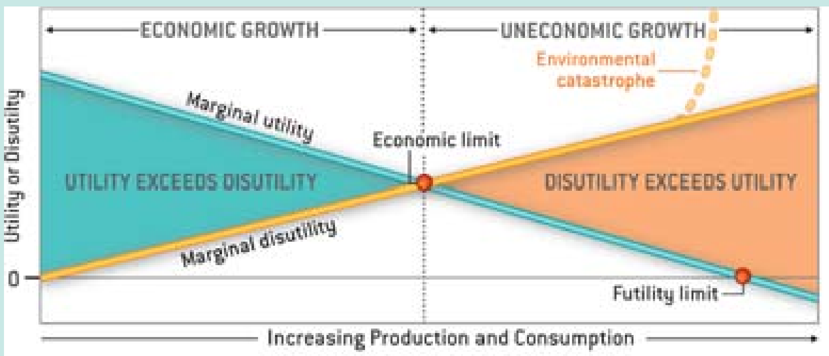
To economists, resources are a form of capital, or wealth, that ranges from stocks of raw materials to finished products and factories. Two broad types of capital exist—natural and man-made. Most neoclassical economists believe that man-made capital is a good substitute for natural capital and therefore advocate maintaining the sum of the two, an approach called weak sustainability.

Most ecological economists, myself included, believe that natural and man-made capital are more often complements than substitutes and that natural capital should be maintained on its own, because it has become the limiting factor. That goal is called strong sustainability. For example, the annual fish catch is now limited by the natural capital of fish populations in the sea and no longer by the man-made capital of fishing boats. Weak sustainability would suggest that the lack of fish can be dealt with by building more fishing boats. Strong sustainability recognizes that more fishing boats are useless if there are too few fish in the ocean and insists that catches must be limited to ensure maintenance of adequate fish populations for tomorrow's fishers.

The policy most in accord with main-

WHEN GROWTH IS BAD

UNECONOMIC GROWTH OCCURS when increases in production come at an expense of resources and well-being that is worth more than the items made. It arises from an undesirable balance of quantities known as utility and disutility. Utility is the level of satisfaction of the population's needs and wants; roughly speaking, it is the population's level of well-being. Disutility refers to the sacrifices made necessary by increasing production and consumption. Such sacrifices can include use of labor, loss of leisure, depletion of resources, exposure to pollution, and congestion.



One way to conceptualize the balance of utility and disutility is to plot what is called marginal utility (*blue line*) and marginal disutility (*orange line*). Marginal utility is the quantity of needs that are satisfied by going from consuming a certain amount of goods and services to consuming one unit more. It declines as consumption increases because we satisfy our most pressing needs first. Marginal disutility is the amount of sacrifice needed to achieve each additional unit of consumption. Marginal disutility increases with consumption because people presumably make the easiest sacrifices first.

The optimal scale of consumption is the point at which marginal utility and marginal disutility are equal. At that point, a society enjoys maximum net utility (*blue area*). Increasing consumption beyond that point causes society to lose more in the form of increased disutility than it gains from the added utility, as represented by the red area of net disutility. Growth becomes uneconomic.

Eventually a population having uneconomic growth reaches the futility limit, the point at which it is not adding any utility with its increased consumption. The futility limit may already be near for rich countries. In addition, a society may be felled by an ecological catastrophe, resulting in a huge increase of disutility (*dashed line*). This devastation could happen either before or after the futility limit is reached.

The diagram represents our knowledge of the situation at one point in time. Future technology might shift the lines so that the various features shown move to the right, allowing further growth in consumption before disutility comes to dominate.

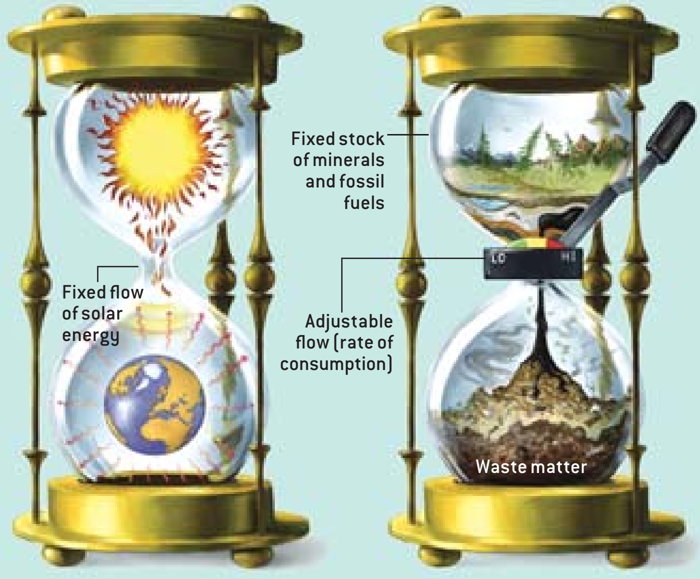
It is not safe to assume, however, that new technology will always loosen limits. For example, discovery of the ozone hole and global warming, both consequences of new technologies, changed the graph as we knew it, shifting the marginal disutility line upward, moving the economic limit to the left and constraining expansion. *—H.E.D.*

JEN CHRISTIANSEN

ECONOMY AS AN HOURGLASS

HUMANKIND'S CONSUMPTION of resources is somewhat akin to sand flowing through an hourglass that cannot be flipped over. We have a virtually unlimited supply of energy from the sun (*left*), but we cannot control the rate of its input. In contrast, we have a finite supply of fossil fuels and minerals (*right*), but we can increase or decrease our consumption rate. If we use those resources at a high rate, we in essence borrow from the supply rightly belonging to future generations and accumulate more wastes in the environment. Such activity is not sustainable in the long run.

Some economists express these facts in terms of physical laws. They argue that this lack of sustainability is predicted by the first two laws of thermodynamics, namely that energy is conserved (finite) and that systems naturally go from order to disorder (from low to high entropy). Humans survive and make things by sucking useful (low-entropy) resources—fossil fuels and concentrated minerals—from the environment and converting them into useless (high-entropy) wastes. The mass of wastes continuously increases (second law) until at some point all the fuel is converted to useless detritus. *—H.E.D.*



taining natural capital is the cap-and-trade system: a limit is placed on the total amount of throughput allowed, in conformity with the capacity of the environment to regenerate resources or to absorb pollution. The right to deplete sources such as the oceans or to pollute sinks such as the atmosphere is no longer a free good but a scarce asset that can be bought and sold on a free market, once its initial ownership is decided. Cap-and-trade systems that have been implemented include the Environmental Protection Agency's scheme for trading sulfur dioxide emission permits to limit acid rain and New Zealand's reduction of overfishing by individual transferable fish-catch quotas.

The cap-and-trade system is an example of the distinct roles of free markets and government policy. Economic theory has traditionally dealt mainly with allocation (the apportionment of scarce resources among competing uses). It has not dealt with the issue of scale (the physical size of the economy relative to the ecosystem). Properly functioning markets allocate resources efficiently, but they cannot determine the sustainable scale; that can be achieved only by government policy.

Adjustments Needed

THE TRANSITION TO a sustainable economy would require many adjustments to economic policy. Some such changes are already apparent. The U.S. Social Security system, for example, faces difficulties because the demographic transition to a nongrowing population is leading to a smaller number of working-age people and a larger number of retirees. Adjustment requires higher taxes, an older retirement age or reduced pensions. Despite assertions to the contrary, the system is hardly in crisis. But one or more of those adjustments are surely needed for the system to maintain itself.

Product lifetimes. A sustainable economy requires a "demographic transition" not only of people but of goods—production rates should equal depreciation rates. The rates can be equal, however, at either high or low levels, and lower rates are better both for the sake of greater durability of goods and for attaining sustainability. Longer-lived, more durable products can be replaced more slowly, thus requiring lower rates of resource use. The transition is analogous to a feature of ecological succession. Young, growing ecosystems have a tendency to maximize growth efficiency measured by production per unit of existing biomass. In mature ecosystems the emphasis shifts to maximizing maintenance efficiency, measured by how much existing biomass is maintained per unit of new production—the

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MATT COLLINS

inverse of production efficiency. Our economic thinking and institutions must make a similar adjustment if sustainability is to be achieved. One adaptation in this direction is the service contract for leased commodities, ranging from photocopiers to carpets; in this scenario, the vendor owns, maintains, reclaims and recycles the product at the end of its useful life.

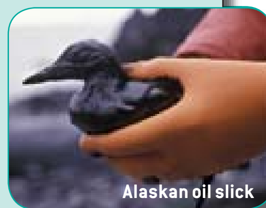
GDP growth. Because of qualitative improvements and enhanced efficiency, GDP could still grow even with constant throughput—some think by a great deal. Environmentalists would be happy because throughput would not be growing; economists would be happy because GDP would be growing. This form of "growth," actually development as defined earlier, should be pushed as far as it will go, but there are several limits to the process. Sectors of the economy generally thought to be more qualitative, such as information technology, turn out on closer inspection to have a substantial physical base. Also, to be useful to the poor, expansion must consist of goods the poor need—clothing, shelter and food on the plate, not 10,000 recipes on the Internet. Even the wealthy spend most of their income on cars, houses and trips rather than on intangibles.

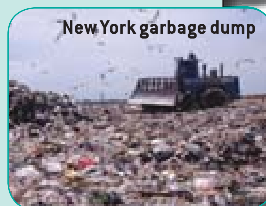
The financial sector. In a sustainable economy, the lack of growth would most likely cause interest rates to fall. The financial sector would probably shrink, because low interest and growth rates could not support the enormous superstructure of financial transactions—based largely on debt and expectations of future economic growth—that now sits uneasily atop the physical economy. In a sustainable economy, investment would be mainly for replacement and qualitative improvement, instead of for speculation on quantitative expansion, and would occur less often.

Trade. Free trade would not be feasible in a world having both sustainable and unsustainable economies, because the former would necessarily count many costs to the environment and future that would be ignored in the growth economies. Unsustainable economies could then underprice their sustainable rivals, not by being more efficient but simply because they had not paid the cost of sustainability. Regulated trade under rules that compensated for these differences could exist, as could free trade among nations that were equally committed to sustainability. Many people regard such restrictions on trade as onerous, but in fact trade is currently heavily regulated in ways that are detrimental to the environment [see "Sustaining the Variety of Life," by Stuart L. Pimm and Clinton Jenkins, on page 66].

Taxes. What kind of tax system would best fit with a sustainable economy? A government concerned with using

MEASURING WELL-BEING


Alaskan oil slick


New York garbage dump

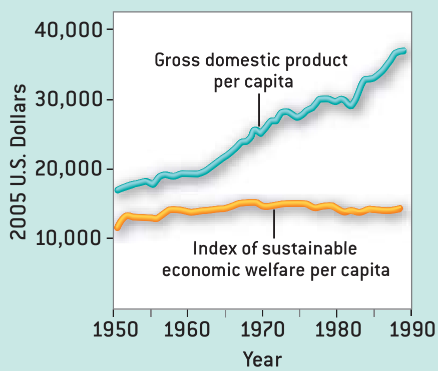
TO JUDGE FROM how gross domestic product (GDP) is discussed in the media, one would think that everything good flows from it. Yet GDP is not a measure of well-being or even of income. Rather it is a measure of overall economic activity. It is defined as the annual market value of final goods and services purchased in a nation, plus all exports net of imports. "Final" means that intermediate goods and services, those that are inputs to further production, are excluded.

GDP does not subtract either depreciation of man-made capital (such as roads and factories) or depletion of natural capital (such as fish and fossil fuels). GDP also counts so-called defensive expenditures in the plus column. These expenditures are made to protect ourselves from the unwanted consequences of the production and consumption of goods by others—for example, the expense of cleaning up pollution. Defensive expenditures are like intermediate costs of production, and therefore they should not be included as a part of GDP. Some economists argue for their inclusion because they improve both the economy and the environment. We can all get rich cleaning up one another's pollution!

To go from GDP to a measure of sustainable well-being requires many more positive and negative adjustments. These adjustments include uncounted household services (such as those performed for free by spouses); increased international debt; loss of well-being resulting from increasing concentration of income (the well-being induced by an extra dollar for the poor is greater than that for the rich); long-term environmental damage such as ozone layer depletion or loss of wetlands and estuaries; and water, air and noise pollution. When all these adjustments are made, the result is the index of sustainable economic welfare (ISEW), as developed by Clifford W. Cobb and John B. Cobb, Jr., and related measures. These indices have been used by ecological economists but are largely ignored by others in the field.

For the U.S., it appears that, beginning in the 1980s, the negative factors in the ISEW have been increasing faster than the positive ones. Similar results have been found for the U.K., Austria, Germany and Sweden. In other words, for some countries in recent years, the costs of growth are rising faster than the benefits.

As important as empirical measurement is, it is worth remembering that when one jumps out of an airplane, a parachute is more beneficial than an altimeter. First principles make it abundantly clear that we need an economic parachute. Casual empiricism makes it clear that we need it sooner rather than later. More precise information, though not to be disdained, is not necessary, and waiting for it may prove very costly. —*H.E.D.*



SUSTAINABLE WELL-BEING in the U.S. has been roughly static even as GDP has grown.

JEN CHRISTIANSEN (*graph*); RANDY BRANDON *Peter Arnold* (*bird*); JAMES LEYNSE *Corbis* (*dump*)

A MEASURED APPROACH

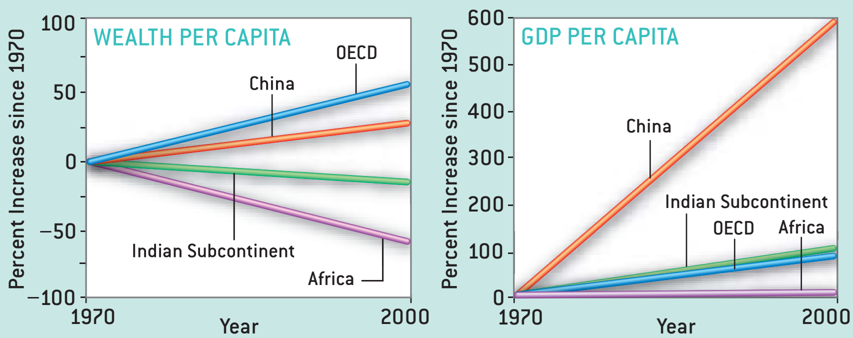
By Partha Dasgupta

MOST CONTEMPORARY economists are optimistic about the future. They observe that the Western world's economic output has increased remarkably since the industrial revolution. They note that this increase has been fueled by the accumulation of produced capital assets (such as roads, machinery, equipment and buildings) and improvements in knowledge, human skills and institutions (such as the legal system). They argue that if knowledge and skills are allowed to accumulate through education and research and development, productivity can be further increased and the world economy will enjoy growth in output for a very long while.

Some economists, however, note that the earth is finite and reject this brand of optimism, instead insisting that we are already using nature's services at or beyond the maximum rate that the biosphere can support in the long term. They argue that policies should immediately be put in place to stop the growth in the use of nature's services. These economists, such as Herman E. Daly and those mentioned in his article, are right to question the optimistic view for its neglect of nature's limits, but they themselves can be criticized on a number of counts. In particular, they are silent on how to reach policy conclusions, and they do not provide a meaningful way to judge the human costs and benefits of stopping any further growth in the use of resources.

A few economists (I am among them) seek to avoid both sets of weaknesses by refining the concept of sustainable development—a path along which well-being across the generations does not decline with the passage of time and may even improve.

As defined by the famous Brundtland Commission Report of 1987, "sustainable development" is development that meets the needs of the present without compromising the ability of future generations to meet their own needs. To achieve this result, each generation should bequeath to its successor at least as much wealth per capita as it itself inherited. Wealth is defined as the value of an economy's entire productive base, comprising man-made capital, natural capital, knowledge, skills and institutions. Economic development should be viewed as growth in wealth per capita, not growth in gross domestic product per capita.



TOTAL WEALTH (*left*) is a better measure of economic health than is GDP (*right*).

There is a big difference between GDP and wealth. GDP includes such factors as purchases of goods and services but does not record the depreciation of capital assets (such as degradation of ecosystems). So GDP per capita can increase even while wealth per capita declines. GDP can be a hopelessly misleading index of human well-being.

How have nations been doing when judged by the criterion of sustainable development? Figures recently published by the World Bank for the depreciation of several natural resources (oil, natural gas, minerals, the atmosphere as a sink for carbon dioxide, and forests as sources of timber) indicate that in sub-Saharan Africa both GDP per capita and wealth per capita have declined in the past three decades (*graphs above*). In contrast, in the Indian subcontinent, even while GDP per capita has increased, wealth per capita has declined. The decline has occurred because relative to population growth, investment in produced capital and improvements in institutions have not compensated for the degradation of natural capital. Moreover, countries that have experienced higher population growth have also lost wealth per capita at a faster rate.

Better news comes from the economies of China and most of the OECD (Organization for Economic Cooperation and Development) countries: they have grown in terms of both GDP per capita and wealth per capita. These regions have more than compensated for the decline in natural capital by accumulating other types of capital assets and improving institutions. It would seem, therefore, that during the past three decades the rich world has enjoyed sustainable development, while development in the poor world (barring China) has been unsustainable.

One can argue, however, that the above estimates of wealth movements are biased. Among the many types of natural capital whose depreciation do not appear in the World Bank figures are freshwater, soil, ocean fisheries, forests and wetlands as providers of ecosystem services, as well as the atmosphere, which serves as a sink for particulates and nitrogen and sulfur oxides. Moreover, the prices the World Bank has estimated to value the natural assets on its list are based on assumptions that ignore the limited capacity of natural systems to recover from disturbances. If both sets of biases were removed, we could well discover that the growth in wealth in China and the world's wealthy nations has also been negative.

The view prevalent in contemporary economics is groundlessly optimistic. Humanity must design institutions and policies that will enable economies to attain sustainable development. To that end, economists now have in hand a framework (estimates of wealth such as the ones given above) for making policy suggestions that are a lot sharper than the cry that humanity must implement a steady-state economy now.

Sir Partha Dasgupta is Frank Ramsey Professor of Economics at the University of Cambridge.

JEN CHRISTIANSEN

SMOKESTACKS are subject to a cap-and-trade system to limit sulfur dioxide emissions. Such policies can help achieve sustainability.

CHARLES FENNO JACOBS *Time Life Pictures/Getty Images*

natural resources more efficiently would alter what it taxes. Instead of taxing the income earned by workers and businesses (the value added), it would tax the throughput flow (that to which value is added), preferably at the point where resources are taken from the biosphere, the point of "severance" from the ground. Many states have severance taxes. Such a tax induces more efficient resource use in both production and consumption and is relatively easy to monitor and collect. Taxing what we want less of (resource depletion and pollution) and ceasing to tax what we want more of (income) would seem reasonable.

The regressivity of such a consumption tax (the poor would pay a higher percentage of their income than the wealthy would) could be offset by spending the proceeds progressively (that is, focused on aiding the poor), by instituting a tax on luxury items or by retaining a tax on high incomes.

Employment. Can a sustainable economy maintain full employment? A tough question, and the answer is probably not. In fairness, however, one must also ask if full employment is achievable in a growth economy driven by free trade, offshoring practices, easy immigration of cheap labor and adoption of labor-saving technologies? In a sustainable economy, maintenance and repair become more important. Being more labor-intensive than new production and relatively protected from offshoring, these services may provide more employment.

Yet a more radical rethinking of how people earn income may be required. If automation and offshoring of jobs results in more of the total product accruing to capital (that is, the businesses and business owners profit from the product), and consequently less to the workers, then the principle of distributing income through jobs becomes less tenable. A practical substitute may be to have wider participation in the ownership of businesses, so that individuals earn income through their share of the business instead of through full-time employment.

Happiness. One of the driving forces of unsustainable growth has been the axiom of insatiability—people will always be happier consuming more. But research by experimental economists and psychologists is leading to rejection of that axiom. Mounting evidence, such as work in the mid-1990s by Richard A. Easterlin, now at the University of Southern California, suggests that growth does not always increase happiness (or utility or well-being). Instead the correlation between absolute income and happiness extends only up to some threshold of "sufficiency"; beyond that point only *relative* position influences self-evaluated happiness.

Growth cannot increase everyone's relative income. People whose relative income increased as a result of further growth would be offset by others whose relative income fell. And if everyone's income increased proportionally, no one's relative income would rise and no one would feel happier. Growth becomes like an arms race in which the two sides cancel each other's gains.

The wealthy countries have most likely reached the "futility limit," at which point further growth does not increase happiness. This does not mean that the consumer society has died—just that increasing consumption beyond the sufficiency threshold, whether fueled by aggressive advertising or innate acquisitiveness, is simply not making people happier, in their own estimation.

A fortuitous corollary is that for societies that have reached sufficiency, sustainability may cost little in terms of forgone happiness. The "political impossibility" of a sustainable economy may be less impossible than it seemed.

If we do not make the adjustments needed to achieve a sustainable economy, the world will become ever more polluted and ever emptier of fish, fossil fuels and other natural resources. For a while, such losses may continue to be masked by the faulty GDP-based accounting that measures consumption of resources as income. But the disaster will be felt eventually. Avoiding this calamity will be difficult. The sooner we start, the better. SA

MORE TO EXPLORE

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HOW SHOULD WE SET PRIORITIES?

BY W. WAYT GIBBS

The world faces no shortage of problems—or of good ideas to solve them. Which should we tackle next? Even as leaders converge on some answers, new markets are being set up to preempt politics

How should humanity progress in the next two generations? Which challenges should we engage, in what order, and with how much sacrifice (if any) of comfort and liberty? There are probably as many distinct responses to these questions as there are thoughtful people on the planet. Not all answers are equally wise, of course, but none can be definitive either. These are ultimately questions about one's moral values and personal preferences.

Experts can help us to understand which problems are most threatening, which solutions are most promising, and how costly it might be to act or to wait. Scientists can exhort us—just as the other contributors to this special issue urge us to focus on ending extreme poverty, securing biodiversity "hot spots," improving agricultural infrastructure, boosting the efficiency of our energy use, and reining in epidemic diseases—yet the experts cannot directly steer the course of humanity.

History emerges from the integration of innumerable choices, as processed mainly by two kinds of imperfect social machines: governments and economic markets. The two are not equally proficient at setting rational priorities and then sticking to them.

Among democracies, even the most effective political machines are typically tuned, by means of election cycles, to find solutions that are at best optimal over the span of a decade or less. Election campaigns use "a new direction" as a synonym for improvement. Persistence is rarely rewarded, and what one legislature or president decrees, a successor cavalierly repeals. The scientific uncertainties that make environmental issues so complex can cause a system of checks and balances to seize up with argument and indecision. The very structure of governments can thus dull their response to multigenerational, interrelated problems of the kind the world must face in the next half a century.

Economists have long argued that for many social and environmental

FINDING THE RIGHT BALANCE among the many competing desires of humanity is no easy feat. Not all trade-offs are obvious, and improving one problem sometimes exacerbates others.

SLIM FILMS


Wealth
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problems, economic machines that direct human competitive and acquisitive instincts toward a global good could achieve greater progress at a quicker pace and a lower price than the "command and control" methods traditionally used by governments. After a long period of skepticism, many regulators, international institutions and philanthropies are now embracing this idea. Markets have been created to slow greenhouse warming, safeguard watersheds, halt overfishing and protect endangered species.

When they are well designed and carefully policed, proponents argue, such markets can become as efficient, self-sustaining and adept at handling risks and uncertainties as a stock exchange. Trading systems make it easier to reconcile the wide range of values that people hold, by letting them express their preferences through a common currency: money. But even among environmental economists, the approach has its doubters, who observe that the details cloaked in the essential qualifiers "well designed" and "carefully policed" are devilish indeed.

The Acid Test

MUCH OF THE CURRENT enthusiasm for market-based regulation stems from the results of a pilot program launched in the U.S. in 1990. Congress amended the Clean Air Act that year to set up a market for the permits that power plants must have to release sulfur dioxide (SO_2)—a major culprit in acid rain—out of their smokestacks. The Environmental Protection Agency began holding annual auctions to sell the pollution permits. Federal law caps the total number of tons of SO_2 emissions that the EPA can sell permits for and lowers the cap periodically; the laws of supply and demand determine the price at which permits for one ton trade.

Regulators hoped that the worst polluters would make relatively affordable upgrades to lower their emissions, so that they could then sell their excess permits at a profit to cleaner plants, for whom further upgrades would be prohibitively expensive. The market would thus direct investments to where they could do the most good for the environment. Smokestack monitors wired to EPA computers keep everybody honest.

According to the EPA, the scheme spurred so much investment in SO_2-removing scrubbers that the cost of the devices fell 40 percent during the 1990s, and their efficiencies rose from 90 to 95 percent. As the cap on SO_2 permits has inched downward, so, too, has the acidity of rain falling on northeastern states.

Economists at Resources for the Future (RFF), a nonpartisan environmental economics institute in Washington, D.C., project that the program will cost about $1 billion a year by 2010—30 to 50 percent less than if the EPA had simply ordered each plant to meet a specific emission standard. The U.S. sulfur dioxide program has been widely heralded as an unequivocal triumph of free market economics and used as a model for other "cap and trade" systems.

But the program's victory is far from complete. The harm the program was meant to remedy—acidity in lakes and streams that cripples their ecosystems—largely remains. A 2001 analysis by Charles T. Driscoll of Syracuse University and nine other scientists concluded that for many watersheds in the Northeast, the emissions reductions schedule set up by Congress is far too timid to achieve full ecosystem recovery within the next 25 to 50 years. The EPA itself

CROSSROADS FOR
GLOBAL PRIORITIES

THE PROBLEM:

- Many global environmental and humanitarian problems will become more pressing over the next 50 years. These issues already compete for a limited supply of attention, effort and money. The struggle for resources could intensify further.
- Governments, international agencies and other major actors have often pursued incompatible or shifting agendas that have failed to fully engage the private sector. When that happens, progress tends to be unnecessarily slow and costly.

THE PLAN:

- In several recent efforts to explicitly prioritize plans of action for addressing global problems, experts from a wide range of backgrounds have agreed on some common solutions that are both feasible and cost-effective.
- Novel markets are being set up around the world to create economic incentives for slowing climate change, improving freshwater management, restoring overexploited fisheries and preserving biodiversity. Ideally these markets will harness human self-interest in the service of the global good. But many of the necessary ingredients for effective markets are still missing.


Tradable fish quotas have succeeded where catch limits have failed

JEFFREY L. ROTMAN *Corbis*

ALL IN FAVOR?

LIKE A RARE ALIGNMENT of the planets, high-profile meetings of economists, politicians, scientists and even rock stars have arrived, all by different paths, at long-term priorities that overlap to a remarkable extent. The Millennium Development Goals, endorsed by the United Nations in 2000 (and described by Jeffrey D. Sachs on page 56), were a common inspiration. The goals emphasize problems rather than solutions, encompass a stunning breadth of ambition, and do not weigh relative costs. So they do not suggest an immediate plan of action. But the U.N. goals do set milestones against which plans can be compared, in contrast to the usual vague mandate to "just do something."

One set of concrete proposals emerged from a controversial meeting of economists in May 2004 called the Copenhagen Consensus. Organized by Bjørn Lomborg, author of *The Skeptical Environmentalist* and then-director of the Environmental Assessment Institute in Copenhagen, the meeting convened a panel of eight well-known economists, including three Nobel Prize winners, to judge 38 proposals for tackling 10 global challenges. Ten proponents and 20 challengers, who were also economists, surveyed previous studies on the interventions and estimated their likely costs and potential benefits. Lomborg then asked the panel to use the cost-benefit analyses to rank the actions to determine how the world could best spend $50 billion more than the international aid that it already contributes.

The economists produced a list but refused to base it solely on the cost-benefit ratios and downplayed the order of the ranking. "Lomborg had an exaggerated impression of how far cost-benefit analysis can take us," commented Thomas C. Schelling of the University of Maryland, one of the judges. "In truth, everything that we ranked as 'fair,' 'good' and 'very good' are all really very good."

The proposals favored by the Copenhagen Consensus panel included, perhaps surprisingly, a host of conventional aid programs. The economists concluded that rich nations ought to spend $12 billion more on distributing supplements of iron, vitamin A and other micronutrients to alleviate malnutrition. An additional $27 billion should go toward increasing condom use and other measures to prevent 30 million people in Africa and Asia from being infected with HIV. And investments in the strategies recommended by the Roll Back Malaria program ought to rise by $13 billion. The small-scale water technologies and community water supplies described by Paul Polak on page 84 got high marks, as did the efforts to combat hunger and infant mortality that Sachs advocates. But the one action that would deliver the highest benefit at the lowest cost, the economists all agreed, is to free global trade from subsidies and tariffs that prop up farms and businesses in rich countries at the expense of those in poor nations and that raise costs for consumers everywhere.

The economists' arguments buttress plans already gestating among politicians and international institutions. Last year the Global Fund for AIDS, Tuberculosis and Malaria announced grants that raise its total commitment to fight malaria worldwide to more than $1 billion since 2002. President George W. Bush declared on June 30 that the U.S. would add $1.2 billion over five years to the

CONSENSUS on alleviating poverty, malaria and debts in Africa emerged from both the Live 8 events (*top*) and the G-8 meeting (*bottom*).

SERGIO DIONISIO *AP Photo* (*top*); VIRGINIA MAYO *AP Photo* (*bottom*)

aid it sends to sub-Saharan Africa for antimalaria programs. And on July 8, leaders of the Group of Eight (G-8) countries promised to contribute an additional $1.5 billion a year to the same cause.

This past January the U.N.'s Millennium Project called for a doubling of aid worldwide to put poor nations, especially those in Africa, back on track to meet the U.N.'s goals for 2015. In July hundreds of thousands of people attending Live 8 concerts in nine countries heard performers urge world leaders to double international aid, cancel the debts of poor nations, and drop subsidies and other trade barriers on agricultural products.

A week later the G-8 leaders pledged to raise their aid budgets enough so that total official development assistance to Africa will rise to $50 billion a year by 2010, more than doubling the level of aid given in 2004. The group also agreed to forgive all the debt that more than two dozen of the poorest countries owe to the International Monetary Fund and two other global finance agencies.

"We want to work with the E.U. to rid our respective countries of agricultural subsidies," Bush said. "I would hope that by 2010 the Doha Round [of international negotiations begun by the World Trade Organization in 2002] will achieve that objective," he added. The WTO will have an opportunity to act on that priority at its next meeting in December.

But as disagreements at the G-8 meeting over greenhouse gas restrictions made painfully clear, the new consensus goes only so far. When it comes to taking action on global warming and other pressing environmental issues, political solutions—such as the Bush administration's voluntary emissions reduction program and the U.N.'s 1992 Convention on Biological Diversity—have not risen to the scale of the challenge. So recently regulators and activists around the world have been trying to rearrange economic incentives in the hopes that market forces will succeed where political will has failed. *—W.W.G.*

has reported that two thirds to three quarters of those surface waters in the upper Midwest, Adirondacks and Appalachian plateau that were acidic in 1990 remained acidic in 2002. During that period, the agency also concluded, the number of acidic waters in New England and the Blue Ridge region did not fall measurably.

The market for SO_2 permits has a flaw in its design, RFF economists observe: because only Congress (and not EPA experts) can adjust emissions caps, the system has not responded to new scientific studies showing that sulfur dioxides are more harmful to humans than previously thought and that acidic waters are recovering more slowly than expected. The lesson is that market overseers need the power, analogous to the Federal Reserve's control over the money supply, to tweak the cap on permits as scientific uncertainties are resolved.

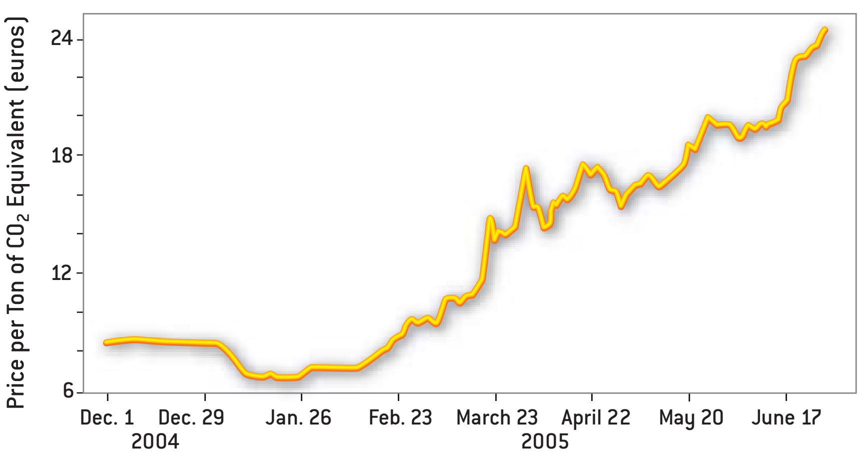
A Change in Climate

UNFORTUNATELY, the lesson was not applied when the rich nations of the world (minus the U.S. and Australia) agreed in the 1997 Kyoto climate treaty to cut their greenhouse gas emissions using an international cap-and-trade system, or "carbon market," which began full operation in the European Union this year. The risks of global warming have grown clearer, but the emissions caps negotiated in 1997 are those that will bind nations through 2012—if other complications with the carbon market do not unravel the treaty first.

Like the Clean Air Act amendments, the Kyoto Treaty created a new commodity literally out of thin air, in this case a permit to emit greenhouse gas with the warming ability of one metric ton of carbon dioxide. Governments hand out these permits to power plants, metalworks and other heavy industries within their borders. Some countries, such as Russia, have a great many more permits than they need, because their economies have shrunk since 1990. (Such permits are considered mere "hot air," however, and are politically unacceptable to many countries.) The supply of permits in Europe overall is smaller than the demand and will tighten further beginning in 2008.

Since the opening bell in January, a scramble among countries and businesses for emissions permits has sent trading volumes soaring as high as two million tons a day. Permit prices have rocketed from around $9 a ton initially to $35 a ton in July, much higher than most economists had expected. For some utilities, the cost of the permits to produce a kilowatt-hour of coal-fired power now exceeds the cost of the coal.

The high prices motivate permit buyers to exploit a novel feature of the carbon market: the trade in "offsets" that represent pollution curtailed by so-called clean development projects set up in developing countries. Factories can use a limited number of carbon offsets as a lower-cost substitute for permits.



SCRAMBLE FOR EMISSIONS PERMITS has sent prices skyrocketing. By July the cost of the permits to produce a kilowatt-hour of coal-fired power exceeded the price of the coal.

At a conference this past February in Amsterdam, venture capitalists described a wide array of offset-creating projects in the works. One in Brazil has covered two large landfills and is burning the methane they emit to generate electricity, thus reducing greenhouse gas emissions equal to 670,000 tons of carbon dioxide annually. Another in China is installing a wind farm to produce clean power worth 51,000 tons of CO_2 abatement a year. Honduras is setting up three small hydroelectric projects that will sell carbon offsets as well as electricity. In principle, the projects allow poorer economies to grow more quickly and cleanly, while helping Europeans meet their Kyoto obligations with less financial pain.

But bureaucratic snafus have thrown the process into crisis. As of the beginning of July, investors had formally submitted about 170 projects for approval by the U.N.-appointed executive board and had begun preparing hundreds of others, but the board had cleared just 12 to enter the market. None of the projects had yet issued any "certified emissions reductions"—the actual fungible offsets—because the U.N. had failed to qualify any financial organization to handle them.

Many of the project managers at the Amsterdam meeting warned that the system will soon collapse unless the U.N. moves more quickly. "If Franz Kafka came back from the grave, he could write a sequel by looking at the procedures of the executive board," lamented Marco G. Monroy of MGM International, which has one approved project and 10 others stuck in the queue.

Without an ample supply of offsets, many countries may have to turn elsewhere to meet their Kyoto targets. Natsource, a consultancy, estimates that the E.U., Japan and Canada will emit roughly 3.5 billion tons more than the treaty allows in the period from 2008 to 2012. Analyst Kristian Tangen of Point Carbon in Norway puts the gap at closer to five billion tons. His firm has forecast that clean-development projects will generate tradable credits equivalent to just 0.03 billion tons by 2007

JEN CHRISTIANSEN; SOURCE: POINT CARBON

A FARM OF THE FUTURE

Ecosystem services previously taken for free could generate perhaps half the income of a farm, if markets for various kinds of environmental credits take off as hoped. Farmlands in the future may have a diverse portfolio of ecosystem services to offer to a wide range of customers.

BIODIVERSITY CREDITS

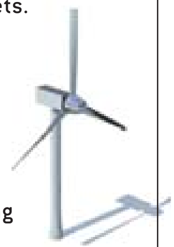
Conservation organizations are leasing development rights from the owners of undisturbed forests and other habitats that host threatened endemic species and fast-vanishing ecosystems.

CO_2 OFFSET CREDITS

When landowners plant new forests and promise never to cut or burn the trees, they can receive carbon dioxide offset credits that industries will buy to help them comply with restrictions on greenhouse gas emissions.

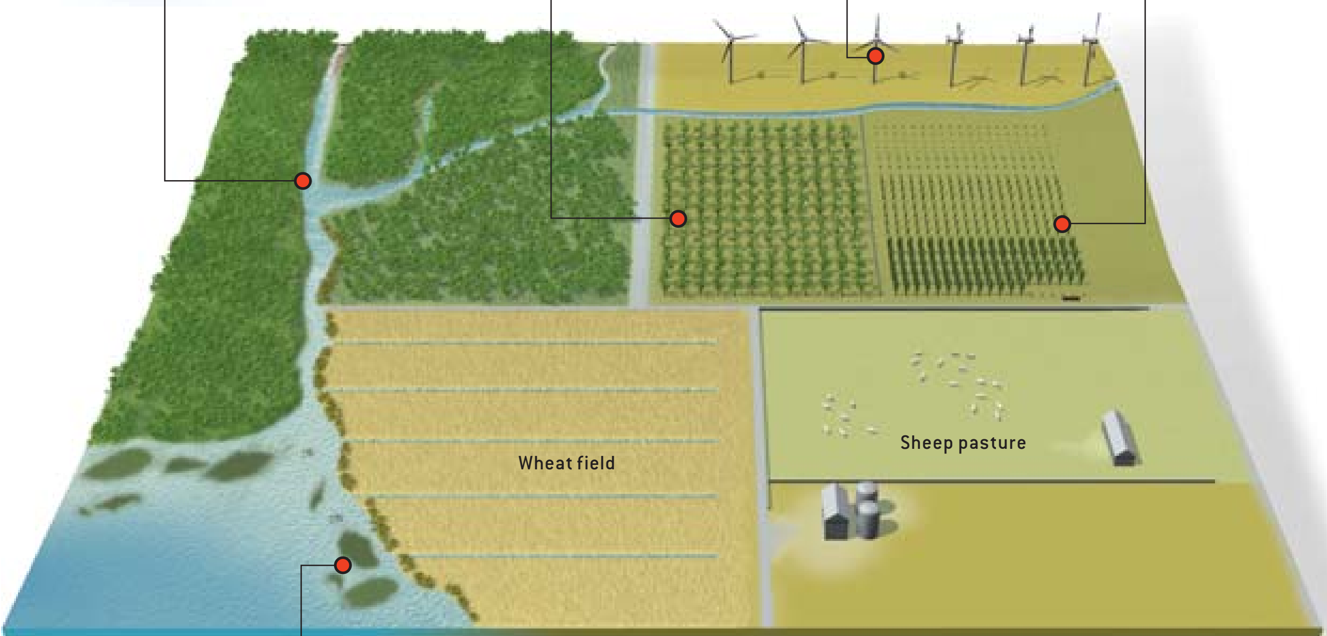
RENEWABLE ELECTRICITY

Wind farms generate nonpolluting electricity that commands premium prices in deregulated power markets. The turbines can also garner tax credits that subsidize their capital and operating costs.



CERTIFIED SUSTAINABLE TIMBER

Sustainably harvested timber is now one of numerous "eco-labeled" products that are certified as ecologically sound and sold at a premium in specialty markets.



WATER CREDITS

Careful management of water and wetlands is economically valuable for many reasons. Urban water authorities purchase water filtration credits to protect the quality of their watersheds; wetland owners can also receive compensation from government agencies for flood-control services, from conservation organizations for the preservation of migratory waterfowl breeding areas, and from agricultural cooperatives for the prevention of soil salinity increases caused by overdrawn groundwater aquifers.

COMMODITY	PERCENT OF FARM'S INCOME	CUSTOMER
Biodiversity credits	5	Conservation trust
CO_2 offset credits	10	Steelmaker
Renewable electricity	15	Power market
Certified sustainable timber	20	Specialty market
Water credits	20	Urban water market
Wheat	15	World market
Wool	15	World market

BRYAN CHRISTIE DESIGN; SOURCE: FORESTS NSW

MAKING MARKETS ON THE ENVIRONMENT

Around the world, new markets are being set up to harness the power of competition and self-interest in the service of the environment. It is still too early to judge whether these new trading systems will succeed, however. Markets work well only when well-defined products enable smooth transactions, when a trusted exchange instills confidence, and when trading volumes are high enough to foster competition.

Market Goal	Products	Suppliers	Customers	Trusted Exchange	Trading Volume
Global warming prevention	**European Union** and **Australia:** permits to emit greenhouse gases equivalent to one metric ton of carbon dioxide; "offsets" and abatement credits for reducing or preventing one ton of CO_2 equivalent	Governments allocate permits; efficiency and greenhouse-gas capture projects create credits	Power generators, metal producers and other industrial sectors; conservation organizations	**E.U.:** multiple exchanges **Australia:** the organization Forests NSW	**E.U.:** permits worth as many as two million tons traded daily **Australia:** 166,000 abatement credits traded last year
Watershed protection	**U.S.:** one-acre units of wetland restored or created **Mexico:** one-hectare (2.5-acre) units of forest preserved	**U.S.:** private wetland mitigation banks **Mexico:** forest landowners	**U.S.:** developers who damage wetlands **Mexico:** water customers and forestry service	**U.S.:** mitigation banks monitored by the government **Mexico:** volunteer inspectors verify compliance	**U.S.:** roughly 23,000 acres of wetlands banked **Mexico:** 770,000 acres under contract
Habitat conservation	**U.S.:** one-acre units of threatened habitat conserved **Costa Rica:** one-hectare units of forest preserved	**U.S.:** private conservation banks **Costa Rica:** landowners	**U.S.:** developers who damage endangered species habitats **Costa Rica:** government, philanthropies	**U.S.:** conservation banks monitored by the U.S. Fish and Wildlife Service **Costa Rica:** government	**U.S.:** about 110,000 acres in conservation banks as of May 2005 **Costa Rica:** about 2.7 million acres
Sustainable fisheries	**U.S.** and **New Zealand:** permits to land a set weight of designated fish species	Governments allocate permits based on analyses of fish populations; retiring fishers sell their quotas	Fishing fleets	Government-licensed brokers and catch inspectors, such as FishServe in New Zealand	Thousands of transactions a year in U.S., New Zealand and other countries

SOURCES: ECOSYSTEM MARKETPLACE; FORESTS NSW; CONAFOR; POINT CARBON

and fewer than one billion tons by 2012.

Short of massive investments in efficiency of the kind proposed by Amory B. Lovins on page 74, the political pressure for these countries to buy "hot air" from Russia may become irresistible. With that in mind, "I personally am not convinced that this instrument will really be effective in addressing climate change," Toshiyuki Sakamoto of Japan's Ministry of Economy, Trade and Industry said at the February conference.

For trading to dent global warming significantly, experts say, the U.S. must participate in the market. That prospect has been rising. Last December the National Commission on Energy Policy urged U.S. legislators to authorize a mandatory cap-and-trade system for climate-warming emissions. In June the U.S. Senate voted on a bipartisan plan proposed by John McCain of Arizona and Joseph Lieberman of Connecticut to do just that—and rejected it, for the second time in two years. Less than a month later, however, the Senate passed a nonbinding resolution in favor of "mandatory market-based limits" on greenhouse gas pollution.

Meanwhile nine Northeastern states have promised to form a regional carbon market. The participants are still hammering out rules for their exchange but are reportedly considering giving utilities in their states the option to purchase allowances from the E.U. emissions trading system and offset credits from clean development projects.

Many experts caution that the carbon market is a high-risk experiment that has yet to face its most serious tests, however. Ruth Greenspan Bell, an analyst at RFF who has worked extensively in Asia, points to accusations of massive energy-trading fraud by Enron and to cases where companies were caught trying to cheat in other cap-and-trade systems in New Jersey, California and the U.K. "If fraud of this sort happens within a well-developed legal system scrutinized by a free press, what are the implications for countries with far less developed property rights and legal institutions to protect markets against corruption and with little public oversight?" Bell asks. "Using markets to control pollution puts high demands on weak infrastructure and bad habits, and the risks are even greater when the commodity is so conceptually unusual and hard to document as polluted air."

Devils in the Details

A WELL-FUNCTIONING market requires many more ingredients than just buyers, sellers and products in limited supply, Bell points out. Competition thrives only when the products are standardized and well specified. Big investors require confidence and liquidity: a trustworthy exchange and trading volumes high enough that players can sell when they want to. Many of the new markets for environmental services are still short of one ingredient or another. And as the experience with sulfur dioxide trading suggests, such a system can function smoothly yet fail to achieve its ultimate environmental goal.

Still, as markets are erected to protect water supplies, conserve habitats and manage fisheries, each takes a step up the learning curve. And even disappointing performance can be better than the alternative. The 1972 Clean Water Act, for example, recognized wetlands' value in purifying water supplies, reducing droughts and floods, and harboring valuable species. The law thus required builders to restore or create as many acres of wetland as they destroyed. Yet marshes and swamps continued to disappear, with more than a million acres damaged by development from 1985 to 1995, according to the U.S. Interior Department.

So the government took a new tack about a decade ago and allowed developers to buy credits from private wetland restoration banks rather than doing the work themselves. Saving wetlands suddenly became a business opportunity instead of a liability. One such bank bought and restored 206 acres of swampland in the New Jersey Meadowlands for $65,000 per acre, then sold credits to developers (who need them to gain approval for construction) at a price of $150,000 per mitigated acre, earning $17.5 million on the deals. Mitigation banks have flourished, and the 500 or so now active in the U.S. have restored some 23,000 acres and sold nearly $300 million in credits, according to Ecosystem Marketplace. In 2003 the U.S. Fish and Wildlife Service started a similar program of conservation banks to help protect endangered species.

In Mexico the national forestry service has begun paying landowners $11 to $15 per acre a year to not log or ranch the land they own in certain regions important to the water supply, biodiversity conservation and mountain ecosystems. Satellite surveillance and volunteer inspectors enforce the five-year contracts, which covered 770,000 acres through last December and will cost the government $150 million or more as it gradually shifts financing to water customers.

The U.S. sulfur dioxide emissions market was hailed as a triumph, but most of the lakes and streams that it was meant to help remain as acidic as ever.

Acid-stricken forests have not recovered

JONATHAN BLAIR *Corbis*

Encouraging as that is, the conserved woodlands are a small fraction of the 620,000 acres deforested in Mexico every year. Expanding the program is difficult, one of its managers notes, because only 15 percent of forested land is privately owned in Mexico, with nearly all the remainder held communally.

Market-based regulation of fisheries more clearly exemplify a "win-win" system. In 1995 the U.S. introduced tradable quotas to regulate the Alaskan halibut fishery, which had collapsed so much that the fishing season was cut to just 48 hours a year. By giving fishers a property right to catch a certain number of fish and by providing an easy way to retire from the business (by selling their quota), the system reduced market gluts—which raised halibut prices and fisher incomes—while allowing the fish population to recover. This year the halibut season is 258 days long. The most expansive tradable quota system, in New Zealand, now covers 93 species.

Even the limited experience so far suggests that at best markets will work well in some regions and for some ecosystem services but will do little for others. One section of the U.N.'s *Millennium Ecosystem Assessment,* released in May, warns that "the promotion of 'win-win' outcomes has been politically correct at best and naive at worst," because although an entire nation or all of humanity benefits from restricting access to a natural resource, it is a few local groups that must bear the costs. Trade will not always allow the many to reimburse the few. That is why, says Robert T. Watson, the World Bank's spokesperson on climate change, markets alone probably will not work. Governments alone demonstrably do not work. The best priorities will wisely alloy the two. SA

W. Wayt Gibbs is senior writer.

MORE TO EXPLORE

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Trading Cases. James Boyd et al. in *Environmental Science and Technology,* Vol. 37, No. 11, pages 216A–223A; June 1, 2003.

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SMART GLASS

Private and Cool

Glass partitions us from other people and the elements, while letting light through. But that transmission can be a problem if we want to have privacy or to block the sun's heat. Smart glass can help, letting us change the properties of windows on demand.

At the push of a button, liquid-crystal glass can rapidly transform from clear to frosted, turning a see-through conference room wall, shower stall or ambulance rear window into a visual barrier [*see illustration, top far right*]. No space-consuming or dirt-collecting shades, curtains or blinds are needed. This "privacy glass" is impossible to see through because it scatters incoming rays, yet the diffusion fills the interior space with natural light.

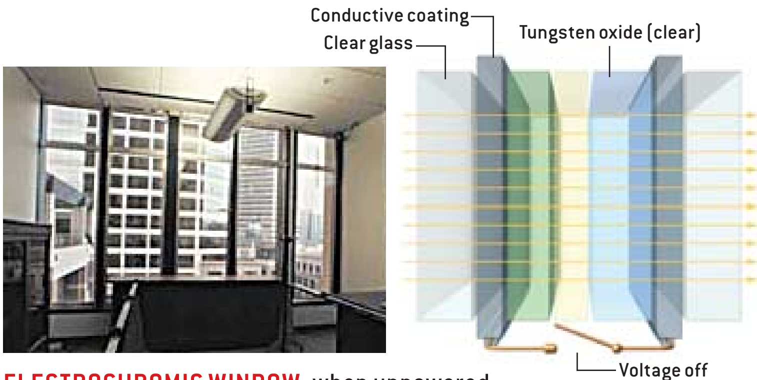
With electrochromic glass, applying a voltage for several seconds to several minutes darkens panels, blocking light [*see illustration, top right*]. When used as windows for buildings, they shade interiors and cut cooling costs. Inhabitants can control the degree of tint, which remains after the power is turned off.

Another option is glass containing suspended particles, which function somewhat the way liquid crystals do. Windows with thermochromic gels that turn white or colored when solar heat surpasses a threshold temperature can cut interior cooling demand, too.

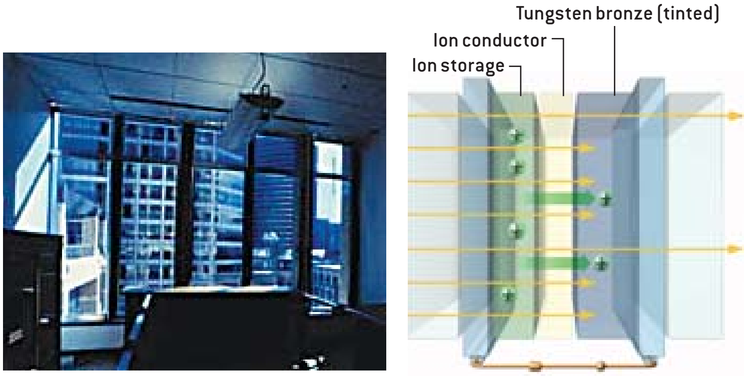
Privacy glass is not more ubiquitous because of the expense, which can be \$100 to \$130 a square foot versus \$10 for standard tempered glass. But customers are becoming more intrigued: "They're using it not just for conference room and bathroom walls but in skylights that block UV [ultraviolet] rays, for privacy between restaurant booths, in bank offices, even for airplane windows," notes Jeff Besse, president of LTI Smart Glass in Lenox, Mass.

The price of electrochromics for energy-efficient buildings may be double that for "low-emissivity" gas-insulated glass, but the larger issue is convincing architects and builders about long-term durability, says Roland Pitts, optoelectronics team leader at the National Renewable Energy Laboratory in Golden, Colo. "The windows must be stable for 30 to 40 years under wide-ranging temperature and solar radiation conditions," he notes, "while switching on and off tens of thousands of times or more." *—Mark Fischetti*

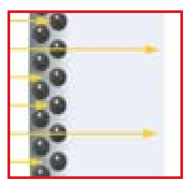
LAWRENCE BERKELEY NATIONAL LABORATORY (*top and middle left*); SMARTGLASS IRELAND LTD. (*top and middle right*); ILLUSTRATIONS BY GEORGE RETSECK



ELECTROCHROMIC WINDOW, when unpowered, transmits light; all layers are transparent.



APPLYING VOLTAGE creates an electric field that drives lithium ions from storage, converting tungsten oxide into tungsten bronze. That layer absorbs ultraviolet and certain visible wavelengths, resulting in a tint. The longer voltage is applied, the darker the tint. Tint remains for long periods after the power is turned off; applying a reverse voltage clears the glass. In an alternative solid-state design, the active inner layers constitute a thin film applied to one pane of glass.



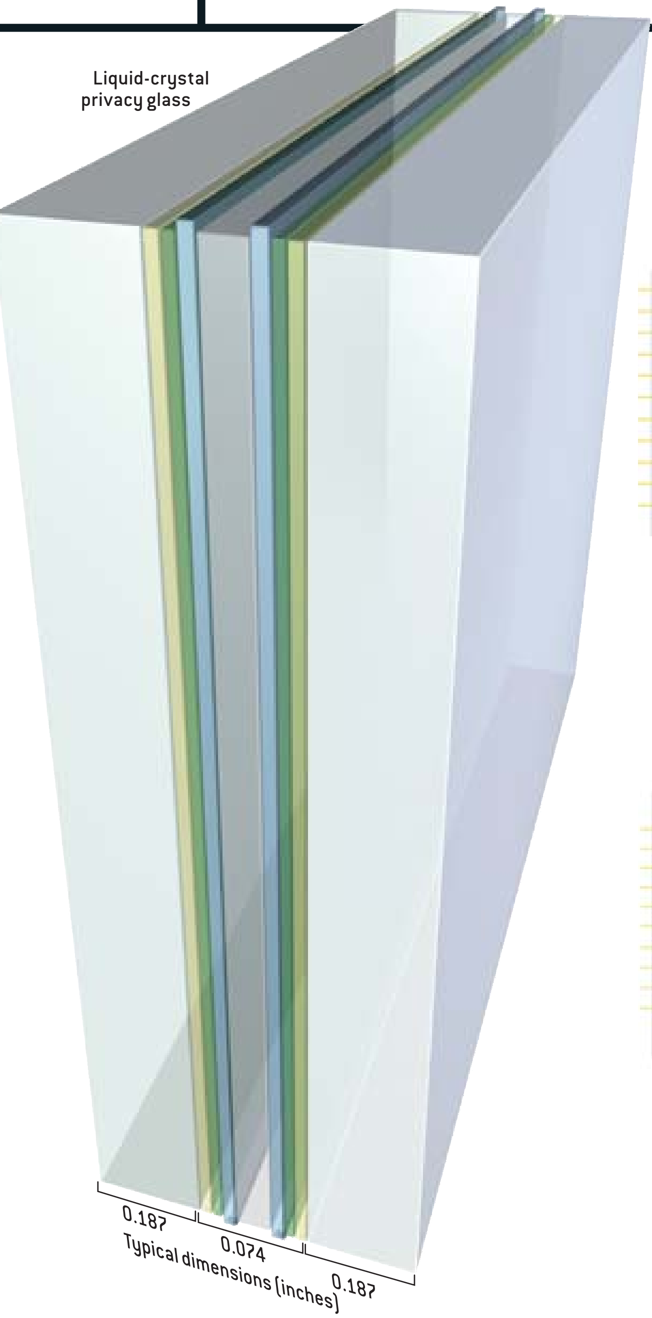
PHOTOCHROMIC LENS is doped with silver halides. The molecules become excited when hit by the sun's ultraviolet rays and then absorb visible wavelengths, cutting glare and darkening the glass. Without UV rays indoors, the lenses lighten.

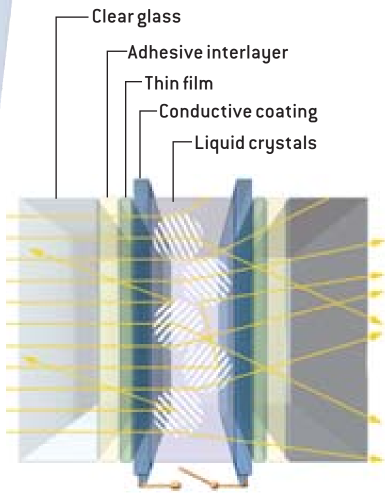
DID YOU KNOW...

CAR COMPETITION: Electrochromic glass is installed in some automobile rearview mirrors so they can be dimmed to reduce glare from headlights. If the glass is used in side or rear windows, drivers could dial in a deep tint when privacy is desired, but these larger areas can take six minutes or more to darken. Makers of liquid-crystal and suspended-particle glass, which switch in less than half a second, are eyeing this market. The heavy tint of windows in certain current automobiles, such as limousines, is permanent.

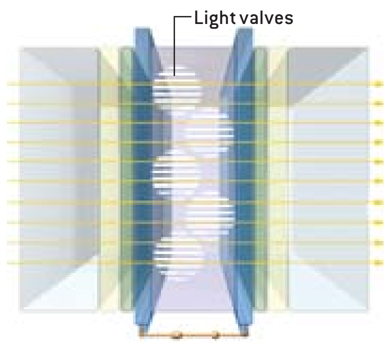
ON A CLEAR DAY: The double-pane glass in most living-room windows transmits only 70 percent of the sun's light (even when clean). Most smart glass reaches that level, too. Automobile windshields, made with a polymer layer between two clear panes that prevents shattering, convey slightly less than 70 percent.

ONE WAY OR TWO: A one-way mirror is a simple pane of glass with a coating on one side that reflects about half the light striking it. In police stations, the reflective side is faced toward a "suspect room," which has bright lighting that reflects strongly off the coating, preventing suspects from seeing through to a darkened room on the other side. Witnesses in the darkness can see through even though only half the rays pass. If the witness-room lights are turned on, transmission toward the suspects improves, and they can see their accusers, albeit poorly.





LIQUID-CRYSTAL WINDOW, when unpowered, appears frosted. The crystals, bound in a clear film, orient randomly, scattering light rays in all directions, making it impossible for the eye to bring into focus an image from outside. Yet light bounces through, so the room interior stays bright.



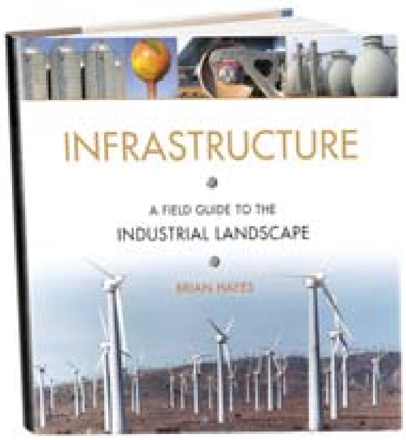
APPLYING VOLTAGE creates an electric field that aligns the crystals. Light valves, or grooves, etched into the crystals allow visible rays to pass in parallel, making the glass appear clear, with a slight haze. The interlayer bonds the film to the glass and blocks UV rays. Power required for the wall shown is less than that for a 100-watt lightbulb.

Have a topic idea?
Send it to workingknowledge@sciam.com

Everything That Isn't Nature

A TOUR OF THE STRUCTURES THAT MAKE UP OUR EVERYDAY ENVIRONMENT **BY ANNE EISENBERG**

INFRASTRUCTURE: A FIELD GUIDE TO THE INDUSTRIAL LANDSCAPE
by Brian Hayes
W. W. Norton, 2005 ($49.95)



Field guides to nature abound, and they are invaluable for pinning down the name of a songbird or hawk that flashes by. Now a veteran science writer has crisscrossed the U.S. photographing and writing a different sort of vade mecum, one to the built environment—the electric-power substations and cargo cranes, cell phone towers, tank farms and derricks that show themselves on highways and country roads, unsung structures as much in need of identification and explanation as any bird.

In the original, highly readable *Infrastructure: A Field Guide to the Industrial Landscape,* Brian Hayes adapts the form of the field guide to "everything that *isn't* nature," as he writes. "There can be just as much of interest happening on a factory rooftop as there is in the forest canopy." The book seeks not just to identify common sights of the technological landscape but to explain how these sights fit together, starting with raw materials like coal, water and food, moving through interconnecting networks like roadways and the electric-power grid, and ending with what he calls the nether end of the industrial economy, waste disposal. "You might as well get to know what it's called and what it does," he writes of this landscape. "It's all around you.... If you would pull off the highway to admire a mountain vista ... you might also consider pausing for a mine or a power plant."

Camera in hand, Hayes spent 1992 to 2004 compiling much of the material for the book, supported in part by the Sloan Foundation's program on public understanding of technology. A technophile, he hopes to change some common attitudes toward the industrial landscape—"In the presence of nature we hold our breath ... in the presence of industry we hold our nose," he writes. He undertakes this task partly through hundreds of photographs taken from airplanes, cars, and the public side of many a chain-link fence, partly through the direct, accessible prose of a man who appreciates the history, engineering, and aesthetics of such wonders as barn hay hoods, grain elevators, oil pipelines, and the ventilation towers of the Holland Tunnel.

Should we never get to some of these sights ourselves—and tours are harder to find since September 11, because authorities have discontinued public access to dams, reservoirs and other installations—Hayes brings us along for a closer look at many of them. Down sewer manholes: "Sounds were deadened. The fragrance was strong but not overpowering." And into the generator gallery of a hydroelectric plant: "The noises are all low notes—hums, buzzes, groanings, rhythmic vibrations that you feel rather than hear." Inside a concrete dam, he describes "a network of galleries and shafts rather like the secret passageways of an Egyptian pyramid."

Along country roads, Hayes explores all the technological sights, from tractors and combines to the history and design of the once dominant technology for enclosing animals, barbed wire: "As light as air. Stronger than whisky. Cheaper than dust," as one of its early proponents described it. The wire was

WATER TANKS, according to author Brian Hayes, often inspire decoration. These examples are found in (*left to right*) Rosemount, Ill.; Rend Lake, Ill.; and Gaffney, S.C.

COURTESY OF W. W. NORTON AND BRIAN HAYES typically stapled to wood posts, but Hayes found a spot in Kansas where wood was in such short supply that posts were carved of limestone, a sight he immediately photographed, of course.

The book is studded with explanations of common but uncelebrated objects—those dumbbells that hang from the undersides of power conductors (to absorb wind-induced vibration); the odd holes in barns (for owls invited in to eat the mice); and the colorful globes on power transmission lines that cross rivers (to alert pilots of tall-masted boats and low-flying aircraft). He explains why the concrete-making truck you are following is turning clockwise briskly (to mix the concrete) or slowly (to keep the aggregate from settling out) and why the plume erupting from the smokestack at the sugar mill isn't menacing (it's water vapor).

Hayes takes on the inevitable thicket of specialized terminology gracefully, adding comparisons to make new terms and processes understandable. A style of floodgates works "like a rolltop desk"; bricks are "sliced from an extruded ribbon of clay by a fine wire, like a cheese cutter." He helps readers appreciate the scale of objects in photographs—for example, the vast machinery of strip mining—by including a nearby object such as a school bus, a car or a Porta Potti. The book ends with an extensive list for further reading, flagged with the word KIDS for younger readers and GEEKS for material more suitable for enthusiasts.

Today, he points out in an afterword, the industrial landscape has become a lonely place, with one crane operator replacing gangs of longshoremen; one gargantuan strip-mining machine, a team of miners. This increasingly automated world is gradually becoming invisible to most of us. "Your home is probably connected to an electric-power substation, a telephone switching office, a water filtration plant," Hayes writes. "Do you know where they are … or what they look like?"

Perhaps after reading this extraordi-

REVIEWS

nary book, more people will be inspired to find out. SA

Anne Eisenberg is a science writer, most recently of the "What's Next" feature for the New York Times, *which appeared from 2000 to 2005.*

THE EDITORS **RECOMMEND**

MISS LEAVITT'S STARS: THE UNTOLD STORY OF THE FORGOTTEN WOMAN WHO DISCOVERED HOW TO MEASURE THE UNIVERSE

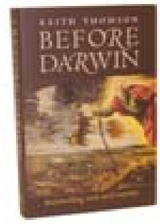
by George Johnson. W. W. Norton (Atlas Books), 2005 ($22.95)

In the early 20th century, colorful, strong-willed astronomers debated the size of the universe: Was the Milky Way just one galaxy among billions, or did it constitute the entire universe? At the same time, in the backrooms of the Harvard Observatory, a not-so-colorful, rather plain young woman was hard at work. Henrietta Swan Leavitt was paid 25 cents an hour as a human "computer": she examined photographic plates, concentrating on variable stars—those that periodically change brightness—looking for anomalies. Eventually she discovered a direct correlation between the time it took a star to go from dim to bright and how bright it actually was—and thus a way to use these stars as a cosmic measuring stick. On the shoulders of her accomplishment, Edwin Hubble was able to prove that the Milky Way is but one galaxy among many.

Little information about Leavitt exists—a few grainy photographs, some letters, no diary. From such scraps, the well-known science writer George Johnson fashions a fascinating picture of her life: her passion for astronomy, the humiliations at the hands of her male colleagues, the constant interruptions of illness, including her growing deafness, and finally her death from stomach cancer at age 53. His grace in bringing her to life is matched by his lucidity in explaining difficult scientific concepts. Unfortunate in life, Miss Leavitt is very fortunate in her biographer.

BEFORE DARWIN: RECONCILING GOD AND NATURE

by Keith Thomson. Yale University Press, 2005 ($27)

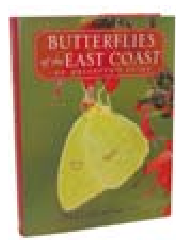


The challenge of scientific findings to religious beliefs goes way back. Thomson, professor emeritus of natural history at the University of Oxford, describes the rapid intensification of the struggle during the 200 years culminating in the heavy blow delivered to Bible-based beliefs by the publication of Charles Darwin's *On the Origin of Species* in 1859. Thomson's focus is on how thinking about evolution developed during those centuries. He reviews the arguments pro and con of such writers as David Hume, Robert Hooke, Erasmus Darwin and William Paley, many of them both clerics and scientific scholars troubled by the ambiguity of their position in the struggle.

But evolution, he says, "is part of a much broader and older enquiry and a deeper contest for our intellectual commitment, a contest between a world system that expects every part of the cosmos ultimately to be explainable in terms of natural properties and processes and one that maintains the existence of a fundamental core of unknowability, of supernatural mystery and the controlling hand of an eternal non-worldly Being." The contest continues today, and Thomson builds a historical foundation for thinking about it.

BUTTERFLIES OF THE EAST COAST: AN OBSERVER'S GUIDE

by Rich Cech and Guy Tudor. Princeton University Press, 2005 ($49.50)



Weighing in at more than three pounds, this book is not intended to be a field guide that you can tuck in your back pocket. But it is easy to use if not to carry, and its girth allows it to be wonderfully comprehensive: 234 species each get their own big page, complete with range maps, color photographs and information on preferred plants.

Go Fourth

NEWS ITEMS CLOSELY, OR DISTANTLY, RELATED TO AMERICA'S BIRTHDAY PARTY BY STEVE MIRSKY

The Fourth of July, only a day ago as I write, features interesting science. For example, fireworks and cookouts involve fascinating chemistry and physics. Some of that hard science leads to nearly 7,000 fireworks-related emergency room visits on and around the Fourth, not to mention cookout-related ER visits (burns, bug bites, food poisoning, ad nauseam) each Independence Day.

The charming Long Island village of East Hampton, N.Y., was spared any potential fireworks mishaps this past Fourth when the local display was canceled thanks to the discovery of plover nests on the beach. But pyrotechnics still occurred, in the form of incendiary quotes from East Hampton resident and advertising legend Jerry Della Femina, who was disappointed that the beach—where the plovers, officially a "threatened" species, were sitting ducks—wouldn't be bombed. The *New York Times* reports that Della Femina asked and answered, "You know why the plovers are endangered? Because everyone hates them." Not so! I think that I have never heard a firework lovely as a bird: I like plovers. Therefore, not everyone hates them, QED, which of course stands for Quintessential Error, Duhhh.

Della Femina owns a local weekly newspaper, in which he groused, "No one wants to hurt the plovers. But has anyone thought that maybe the little bastards have reached the end of the line and they are going to die?" Now, *Scientific American*'s offices happen to be on advertising's Main Street, New York City's Madison Avenue, where I get to absorb the local culture. So it's beyond me why an ad man would go out of his way to insult the 40 million Americans who spend $32 billion annually on bird-watching, according to the U.S. Fish and Wildlife Service. Maybe he likes to eat crow.

On to the workings of other birdbrains. The July 1 issue of *Science* included a study that tracked how birds negotiate areas that have been mostly deforested but still have so-called landscape corridors. These thin strips of original habitat are maintained in the hope that wildlife will take advantage of them during migrations. Working under the theory that what goes in must come out, the researchers sprayed wax myrtle seeds, an enormous hit among eastern bluebirds, with a harmless fluorescent powder. The birds' droppings thus lit up like the Fourth of July, enabling scientists to easily see that birds do indeed use the corridors, QED, which, as everyone knows, stands for Quantify Every Doo.

In other July Fourth food news, Takeru Kobayashi again won the Nathan's Famous Hot Dog Eating Contest at Coney Island. That's five years in a row for the diminutive Japanese wiener jammer, who downed 49 dogs in 12 minutes and did not end up in an emergency room, QED, which, as has long been true, stands for Quite Extraordinary Digestion.

At a regional qualifying event before the finals, a spokesperson for the International Federation of Competitive Eating claimed, "They say that competitive eating is the battleground upon which God and Lucifer waged war for men's souls, ladies and gentlemen. And they are right!" (Well, maybe—neither supernatural being returned my requests for verification.) Actually, really serious competitive eating happens everywhere year-round, if you include predators competing with one another over prey and herbivores competing with one another over herbs, QED, which self-evidently stands for Quit Eating = Die.

Finally, just a few days before the Fourth, researchers reported that fishers in Thailand had caught a catfish that weighed in at—we're gonna need a bigger boat—646 pounds. Known as a Mekong, rather than a King Kong, catfish, the critter was almost nine feet long. The captors were hoping to sell the endangered species member to a consortium of conservation groups, who in turn were going to release it. At which point the fishers no doubt hoped to catch it again, rinse, repeat. Unfortunately, the big beast died in captivity, leading to a giant sushi feast somehow missed by Takeru Kobayashi, QED, which obviously stands for Quiescent Entrails, Doc. SA

ILLUSTRATION BY MATT COLLINS; PHOTOGRAPH BY FRANK VERONSKY

Are food cravings the body's way of telling us that we are lacking nutrients?

—J. Shelton, Ogden, Utah

Peter Pressman of the Cedars-Sinai Medical Center in Beverly Hills, Calif., and Roger Clemens of the University of Southern California School of Pharmacy explain:

A hankering for particular foods is not linked to any obvious nutrient insufficiency. But other biological factors appear to be at work.

Researchers have employed functional magnetic resonance imaging (fMRI) to explore the neural basis of such appetites. The images suggest that when somebody is pining for a certain fare, brain components in the amygdala, anterior cingulate, orbital frontal cortex, insula, hippocampus, caudate and dorsolateral prefrontal cortex are activated. A network of neural regions may be involved with the emotion, memory and chemosensory stimuli of food yens.

Desire for chocolate offers an example. The treat's constituents may influence satiation or alter our longing for it by affecting mood-influencing chemicals in the brain, such as phenylethylamine, tyramine, serotonin, tryptophan and magnesium.

Additional factors such as simple carbohydrate content may amplify a food's appeal or even attenuate depression. More support for a nutrition-neurological connection comes from research that shows that administration of naloxone, an agent that blocks opiate receptors in the brain, appears to inhibit the consumption of sweet, high-fat foods—chocolate among them. Studies of cannabinoids, which commonly occur in marijuana, have shed more light on the neurochemistry of selective appetite. In addition, research has identified an entire spectrum of gut neuropeptides with elaborate central nervous system feedback and influence on satiety.

Some studies suggest that chocolate craving, especially among women, may partly result from a sense of deprivation or a reaction to stress, hormonal fluctuation and modulation of neuropeptide concentrations. Culture has an influence as well. Spanish women, for example, eat relatively large quantities of chocolate and exhibit limited craving for that sweet. In contrast, American women consume less yet present a strong "chocophilic" tendency.

What causes feedback in a guitar or microphone?

Robert L. Clark of the Pratt School of Engineering at Duke University offers this answer:

Several mechanisms can lead to the unpleasant shriek known as feedback. Let us deal first with the simple case of a microphone and an amplified speaker. Feedback occurs when a "loop" closes between an input (the microphone) and output (the amplified speaker). The sound radiated from the amplified speaker reaches the microphone and is subsequently amplified again and again, until it saturates and can no longer amplify the input. This excessive ratio of output to input, called gain, occurs at a particular frequency and arises from many factors. These can include the distance between the microphone and the speaker, the directional design of the microphone and speaker, the influence of reflective surfaces within the acoustic environment, and the presence of additional microphones and amplified speakers. To reduce gain, an equalizer can adjust the signal amplification.

When a microphone is used with an acoustic guitar, the amplified speaker closes the loop between the input and output when the radiated sound from the speaker reaches the guitar. In such cases, the guitar starts vibrating excessively at a particular frequency (typically between 100 and 200 hertz), or the room itself can begin to resonate, producing an audible tone. A similar mechanism occurs in electric guitars. Structural vibrations induced by acoustic feedback can magnify the signal generated by sensors embedded in the guitar to "pick up" its sound, leading to the instability of feedback. SA

For a complete text of these and other answers from scientists in diverse fields, visit www.sciam.com/askexpert

MATT COLLINS